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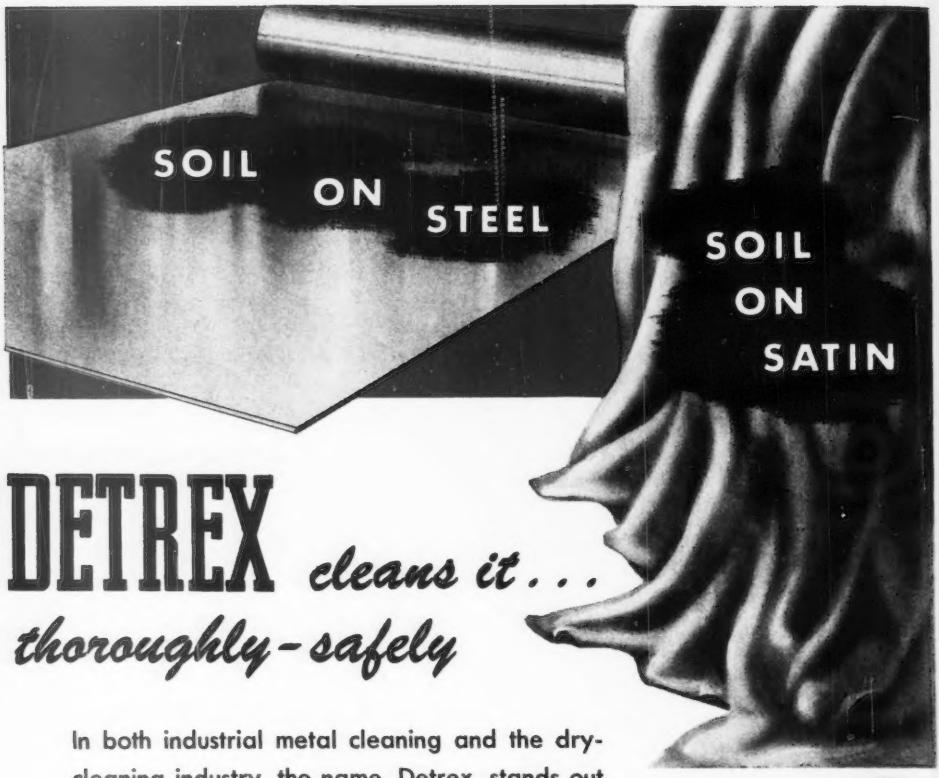

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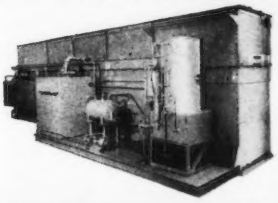

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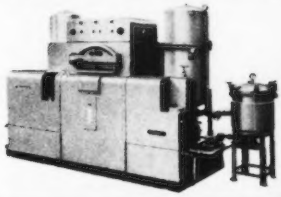

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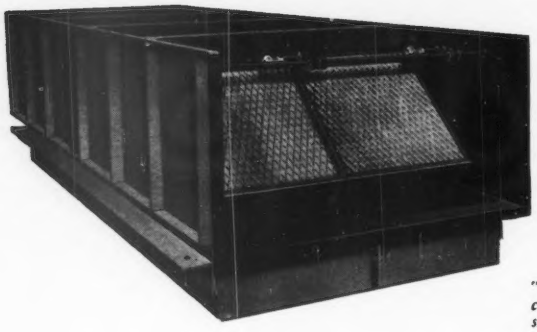

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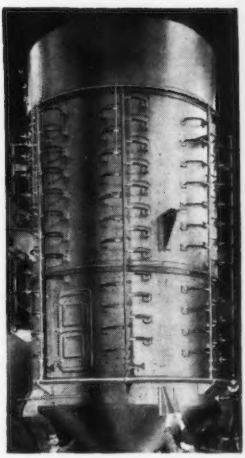

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Automatic Audiometry for Industry?

RAYMOND CARHART, Ph.D.
School of Speech and Department of Otolaryngology
Northwestern University, Evanston, Illinois

THE QUESTION as to whether automatic audiometry is to be integrated into industrial programs for hearing conservation can have only one long-term answer. Here, as elsewhere, automation is on the way. However, as elsewhere, its role must be understood realistically if its contributions are to be most effective. The present status of automatic audiometry has a bearing on how one may best incorporate it into industrial medicine. Furthermore, its inherent limitations and advantages must be assessed if one is to avoid either an overzealous acceptance or a pessimistic restriction of the methodology. Above all, one must evaluate automatic audiometry as a procedure for *testing the capacities of human beings.*

The ultimate purpose of any automatic technique is, of course, to yield measures which are either more reliable or more economical than can be obtained by manual methods. It is generally accepted that loss of threshold acuity shall be the indicator for degree of impairment. Likewise, it is agreed that acuity shall be explored with pure tones. It is assumed that such measurements can (1) furnish a record of preemployment hearing acuity; (2) indicate whether hearing has shifted since employment began; (3) help isolate the noise-susceptible person; (4) aid in the diagnosis of ear disease and, hence, in determining legal responsibility for any impairment which may appear, and (5) supply the basis for legal computation of auditory disability. The question at hand is how adequately data gathered automatically can serve these purposes.

As a prelude to assessing automatic methods, it is well to remember that manual audiometry has been used in a variety of ways, not all of which are equally applicable to industrial circumstances. The conventional threshold test, which is administered to one person at a time, satisfies industrial requirements excellently. Conversely, the more rapid individual sweep check, which has proved so effective in public school programs for hearing conservation, falls short in industrial situations because it is a screening device that does not designate specific thresholds. Similarly, group audiometry varies in usefulness with the specific methodology involved. Screening procedures, such as the Massachusetts[7] and the Glorig[5] tests, have their main application elsewhere. However, there are several group methods which yield detailed audiograms and which, theoretically, could be employed in industrial programs. Illustrative of these methods the one devised by Harris.[6] Unfortunately, while these group methods would allow one to process a large number of workers per day, they suffer the following disadvantages: (1) the time each man is away from work is not reduced, (2) the equipment is relatively involved and expensive, (3) a large testing room with superior acoustic characteristics is required, (4) opportunities occur for subjects to cheat or to disturb one another, and (5) the methods become more cumbersome as the range of losses to be covered is increased. In consequence, there has been a tendency to ignore group tests in planning programs of industrial audiology. However, if such tests win new favor in the future, it will be simple to automatize them.

To date, the designers of automatic audiometers have concentrated on procedures which test each subject separately. Two de-

sign trends have already reached the practical stage. One has culminated in the Rudmose[9] unit, which is a simplification of von Békésy's[1] original procedure for automatic threshold tracing. The other is Brogan's[2] system for simulating conventional audiometry.

The fundamental feature of the Rudmose audiometer is that the test stimulus is presented as a continuous tone. The subject controls the intensity of this tone through a switch. The intensity decreases so long as he presses this switch and increases when the switch is released. The subject is instructed to keep the tone hovering between inaudibility and audibility. The outcome is printed directly on an audiogram chart as shown in Fig. 1. The vertical position of the serrated line on the chart records the intensity level at which he kept the tone on the brink of audibility, while successive horizontal positions indicate the various test tones employed. The tracing for each such tone consumes about half a minute and the entire sequence is completed for one ear before testing the second.

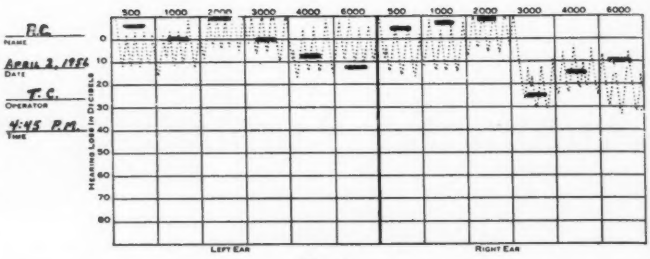

Fig. 1.
Audiogram obtained with the Rudmose instrument. Wave-like tracing is the record of hearing yielded by the unit. Horizontal marks superimposed upon this tracing are the thresholds for the same subject when measured with a manually-operated audiometer.

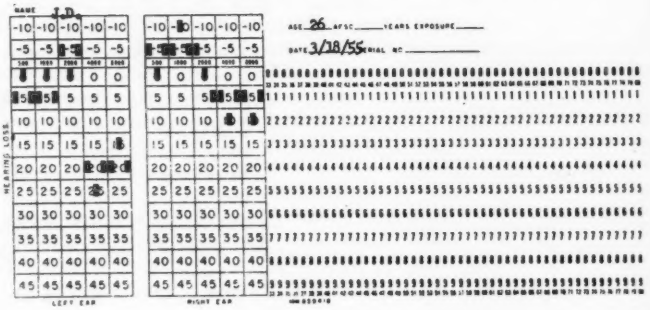

Fig. 2.
Audiometric record punched directly on a special IBM card by the Brogan instrument.

The Brogan audiometer operates on a different principle. The test at any one frequency requires a standard number of stimulus presentations. Each presentation is a steady tone one second in duration. The intervals between tones are varied randomly in length. The initial presentation is at a moderately high intensity level. If the subject hears this tone, he presses a signaling device. In consequence, the audiometer decreases the intensity of the next presentation by ten decibels. The process continues each time the subject signals, while the succeeding tone is made five decibels more intense when he fails to signal. All subsequent changes, each in the appropriate direction, are of five decibels. In essence, then, the subject "zeros in" on his threshold during the early presentations and thereafter keeps the instrument bracketing at this intensity. The machine records the levels of the last three tone presentations. Brogan originally had the results printed as numerals on ticker tape, but he has more recently punched the results as an audiogram directly on a special IBM card (See Fig. 2).

The contrasts between the Rudmose and the Brogan systems, not all of which have been mentioned, emphasize the fact that no single methodology is essential to automatic audiometry. Webster expressed the situation well when, at the 1955 meeting of CHABA, he stated that any psychophysical procedure applicable to clinical audiometry could be automatized. Similarly, there is wide latitude in the physical arrangements

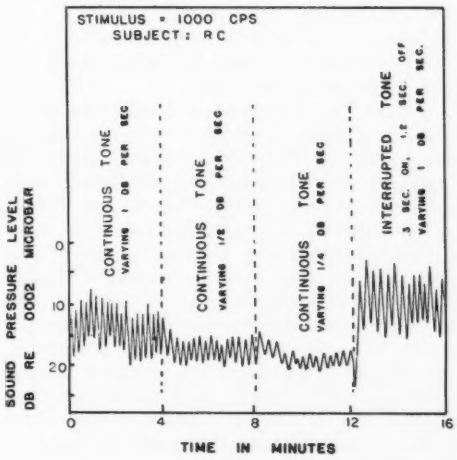

Fig. 3.
Consecutive Bekesy-type tracings illustrating the persisting effect of mild auditory exposure, and the influence of type of stimulus, on threshold level.

which are possible with any system. For example, a battery of audiometers can be operated from a centralized control room connected to a series of test cubicles. Brogan, whose primary concern has been to develop a procedure for testing large numbers accurately in military situations, designed his unit to fit such a plan. The important point is that his audiometer can be used where only one person is tested at a time. Conversely, Rudmose's unit was developed to do individual testing, but a multiple array of these units could be assembled if one desires. Therefore, one must avoid thinking exclusively in terms of either a particular type of automatic audiometer or a specific physical arrangement.

Moving to another point, the industrial physician who wishes immediately to incorporate automatic audiometry in his company's health program must be aware that our knowledge is still limited. A series of technical questions still await answer. The most pressing of these questions, which fortunately is being attacked through such studies as the Wisconsin State Fair survey, deals with whether a particular method of automatic audiometry yields thresholds which are comparable to those obtained by the manual method.

To explain: it is easy to demonstrate that the level at which threshold is recorded can be changed markedly by the conditions of automatic audiometry. Two factors having such effects are illustrated in Fig. 3. The figure shows five Békésy-type threshold tracings for a 1000 cps tone. The first four drawings, reading from left to right, were obtained with a continuous tone whose intensity was shifting at a rate of 1 db per second. The subject determined the direction of the intensity shift by pressing a switch when he was aware of the tone.

The first tracing records the responses immediately after the subjects had entered the test chamber from the waiting room, which was reasonably quiet. Note that the threshold stabilized after a short and minor drift. Next, the tracing was stopped and the subject was exposed to a steady 1000 cps tone only 20 db above the threshold he had just traced. Immediately thereafter threshold tracing was resumed. Note that initially the subject suffered a 10 db deterioration in threshold, that he eventually stabilized at a somewhat better level, but that this level was approximately 5 db poorer than his first tracing. Interestingly enough, as shown by the third tracing, the subject returned to the original level after being allowed a three minute rest without any auditory stimulation. A second minute of exposure to the 1000 cps tone at 20 db above threshold again caused an initial deterioration of 10 db with ultimate stabilization at the intermediate level. It is disturbing to see how much a subject's threshold tracing for an uninterrupted stimulus may be influenced by the listening experiences to which he is exposed immediately before he is tested.

It is equally disturbing to realize that as radical a variation can be caused by changing the nature of the stimulus. This fact is illustrated by the final segment of the record in Fig. 3. Note how the tracing suddenly jumps to a level some 6 db better than any level recorded previously. The only change in conditions was that the stimulus was now interrupted for 1.2 seconds every 1.5 seconds. Here is an illustration of a fact which has been demonstrated in many ways, i.e., Kopra[8]: namely, that, under many circumstances tracings for interrupted tones record responses to fainter sounds and are less

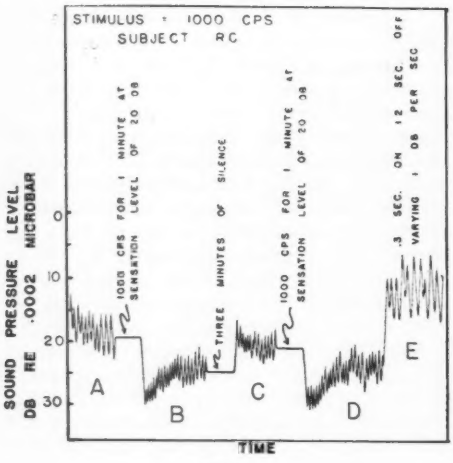

Fig. 4.
Consecutive Bekesy-type tracings illustrating the effect of rate of intensity modulation upon threshold level.

susceptible to environmental influences than are tracings for uninterrupted tones.

Other factors also influence the kind of record which the Békésy-type instrument yields. Fig. 4 illustrates one of these factors. Again, the stimulus is 1000 cps. Note the progressive narrowing of the excursion which characterizes the first three segments of the record. This narrowing resulted because the rate of intensity change was reduced from 1 db per second to ½ db per second and, finally, to ¼ db per second. Observe particularly that the narrowing was achieved by a shift in the upper boundary of the tracing. This boundary records the level at which the tone becomes inaudible. The lower boundary, the point at which the inaudible stimulus is re-heard, remains essentially stable. These facts pose a bothersome question: namely, since both the upper boundary and the midpoint shift with the rate of intensity change, what point on the tracing represents threshold? The error introduced by choosing the wrong facet of the tracing may be sizeable, particularly for a tracing made with the rapid intensity changes necessary to keep testing time within practical limits.

Incidentally, the last segment of Fig. 4, which was obtained with the interrupted tone described earlier, shows that the interrupted tone yielded a tracing with wide excursions, so that the problem of how to read the tracing is not eliminated by changing the type of stimulus.

Please do not misunderstand the foregoing remarks. They are *not* intended to argue either that interrupted tones are superior as stimuli or that the Békésy-type procedure is undesirable for industrial purposes. The remarks merely have the purpose of exemplifying some of the uncertainties which exist at the moment. Similar questions could be raised about other methods for automatic audiometry. The time will come when research has delimited relationships among methodologies and has isolated critical test conditions so that one may compare with confidence the results obtained by different procedures. Meanwhile, there is no reason why one should not employ the methods of automatic audiometry at his disposal *provided he recognizes temporary limitations in interpreting findings.*

The great danger lies in embracing automatic audiometry uncritically because of the belief that it is a means of reducing expense or of escaping the inadequacies of our past testing programs. The truth is that neither of these advantages is assured.

For one thing, there are minor limitations to the automatic equipment which is commercially available today. Its calibration is technically good and electronic performance is well controlled. However, a relatively precise balance of mechanical function must be maintained. Moreover, an operator must prepare the instrument anew for each succeeding subject. These considerations, plus the fact that the task to be performed by the subject requires appreciable insight and understanding, mean that a well-trained operator is currently needed to obtain valid results with an automatic instrument. The situation is rather well epitomized by the reactions of an entire group of clinicians who recently undertook to test a broad sampling of subjects with an automatic audiometer. The group reached the conclusion that the instrument lessened the manual task for the operator, but that he was left with an unchanged responsibility to maintain a running evaluation of both the instrument and the subject as the test progresses.

Mechanical improvements and revisions

in procedure are to be expected, with resultant simplification for all concerned. However, the basic task of audiometry will always be to cope with human beings who differ in abilities, in willingness to cooperate, and in motivation. For one thing, this fact means that every staff in industrial audiometry must include persons with firm knowledge of test instruments and their clinical maintainance, with adequate information on human hearing and the methods for its assessment, and with ample awareness of the manifestations and types of auditory impairments. Moreover, the persons actually engaged in gathering test data must have reasonable training and experience if they are to avoid accepting false or erroneous responses unwittingly. Stated dramatically, the automatic audiometer cannot become a complete substitute for clinical judgment and human wisdom.

All will agree that the personnel in an audiometric program must be competent if results are to have full medical and legal value. Opinions differ as to the amount and type of training which yields such competence. One can not argue strongly for a particular manner of acquiring this competence, but one should always plead that the training be a realistic rather than an expedient minimum. Far too frequently it is felt that a few hours of instruction, or possibly even the reading of a pamphlet, is ample to prepare an audiometric technician. Under these circumstances, the person may learn a bit of special lingo, may discover how to twirl dials on a particular class of instrument, and may be taught to draw neat audiograms. But, without further guidance, the person cannot acquire any real understanding of the electro-acoustic, the auditory, or the psychological principles which are implicit in valid audiometry. The product is a person without the wherewithal to cope with any unusual development in the audiometric program.

It is more difficult to define a realistic minimum of training than to condemn an inadequate plan of instruction. One university has felt that it can mobilize its facilities so as to present this minimum in a six-week summer program of full-time academic study. The goal is to make an intensive orientation in audiology available to mature persons who wish this orientation for industrial or clinical purposes. Other institutions and organizations have their own means for making similar realistic minima of training available.

Obviously, the foregoing remarks express the belief that the total job of audiometry for industry can never be accomplished automatically. As supporting evidence consider the situation one faces whenever an automatic test indicates that a worker's hearing may have become poorer during employment. There is the possibility that this shift in hearing is a willful fabrication, that the worker is malingering. This possibility is particularly likely if the man is approaching a termination in his employment or is otherwise facing circumstances which might encourage him to open claim for damage. In the presence of such a possibility it becomes necessary to re-test the worker's hearing. It may also become necessary to conduct special examinations, such as the Doerfler-Stewart[3] test. In either event, the additional audiometry must be administered personally by an individual with sufficient training and experience to unearth the fact of malingering if it is present. The discovery of malingering is always a mental contest wherein the examiner pits his skills and professional technique against the astuteness and duplicity of the malingerer. Obviously, here is a task which cannot be relegated to any technician who happens to be on hand. Here is a task which calls for an examiner of sufficient competence so that the findings will furnish a reliable basis for company action and will have as much legal status as possible.

These are other examples of the need for informed follow-up on some of the results obtained through automatic audiometry. The physician has the problem of determining when a threshold shift indicates a noise-susceptible person. He must integrate audiometric findings with other data in reaching a specific diagnosis of ear disease. Finally, he must be protected against audiometric errors which may arise from inattention or poor understanding on the part of the worker. In other words, industry's audiometric programs must be sufficiently humanized and personalized to cope with the special demands as they arise.

Stated differently, one is not faced with choosing between alternatives when he asks

the question, "Audiometric audiometry for industry?" Every program will come more and more to rely upon mechanized methods in obtaining records of hearing prior to employment and at periodic intervals thereafter. Every program will also find it necessary to maintain facilities for conventional audiometry. It is even likely that many programs will come to incorporate some special tests which are not now considered a fundamental part of industrial audiometry. The choice of procedure in a given instance will then depend upon the purposes of the moment and the use to which the findings are to be put.

The biggest danger, as industry proceeds to integrate automatic audiometry into its health programs, is that it will be influenced by transitory considerations. For example, there is the question of the speed with which a record of hearing can be obtained. A competent audiometrist can test eight to ten workers per hour, while one contemporary automatic audiometer will process about the same number in the same time. Again, the automatic instrument is two to three times more expensive than its manual counterpart and its maintainance is likely to be higher. On the other hand, when the work load is great enough, salary costs can be reduced by having one operator supervise three or four automatic units. However, the important point is that such relationships can change almost momentarily and that they do not, even temporarily, approach the crux of the economic issue.

The total costs of any industry's program for hearing conservation includes five prime items. Only two of these items, audiometers and audiometricians, have been discussed above. The major expense is concentrated in the other three, and this expense is relatively independent of the test procedures employed. For one thing, a substantial budget is necessary to maintain a good program in the control and reduction of plant noise. Secondly, adequate testing rooms and proper supervision of the audiometric program constitute an essentially fixed cost. Finally, and of greatest financial importance, are awards for hearing loss paid to workers. A major purpose of the industrial programs in noise reduction and hearing conservation is to keep the number and magnitude of such awards to a fair minimum. All of us are aware of the financial savings, as well as of the human benefits, resulting therefrom.

In consequence, the basic concern when one is choosing among audiometric methodologies should be the ultimate precision and the legal validity of the results. The direct costs of the methodologies themselves are not the major item. Moreover, these will change from year to year as equipment and procedures evolve. The prime requirement, for both legal and medical reasons, will always be that the program must be staffed by competent personnel whose findings and judgments can be trusted. These people must have at their disposal a flexibility of technique and equipment which will allow personalized exploration of hearing when circumstances demand. They must also have the advantage of automatic and simplified procedures for gathering the more routine audiological data.

In other words, an individual who is planning a complete audiometric program for his industry should not consider his task as one of choosing between automatic and manual techniques. He should view the job as one of integrating the two methodologies in the manner best suited to his situation. A large amount of automatic audiometry can be introduced immediately by big concerns with a heavy daily load of hearing tests. Conversely, automatic audiometry is probably an unwise luxury, at the moment, for many a small company with a limited test load. There is little point in having duplicate equipment when the demands are on a part-time and sporadic basis, since here automation offers but little saving in either time or effort. Moreover, the small company may not yet have solved the problems of procuring adequate personnel or of obtaining suitable testing quarters. Until these problems are met, other questions, such as the usefulness of automatic audiometry in the company's program, remain academic.

In truth, this situation applies regardless of a concern's size. Every audiometric program worthy of a company's confidence and pride must start with a staff trained to do the job properly. In the hands of such a staff, automatic audiometry will make an essential and valid contribution to the total program.

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Industrial Hygiene Branch, Health and Safety Laboratory
U. S. Atomic Energy Commission, New York City

Three investigations at three different levels of volume up to approximately 10 tons have been conducted. These involved burning of contaminated laboratory wastes containing millicurie amounts of activity in an uncontrolled open field. Extensive sampling of the area out to a distance of 2,000 feet revealed negligible contamination of the air and negligible fallout under the conditions of test.

THE OPERATION of a radiochemical laboratory almost of necessity results in the generation of relatively large quantities of contaminated burnable waste materials. These materials are the familiar Kleenex, Diaper paper, and other absorbent materials, rubber gloves, wooden table tops, and so forth. With the expanding scope of the Atomic Energy Program, the quantities of such materials in many cases become overwhelming. It is increasingly evident that a practical, economical means must be devised for disposition of these wastes, which at the same time is consistent with the danger which might arise from them.

In the past, such materials have either been baled and stored above ground; incinerated in large very costly incinerators; buried under the ground and covered; or weighted with concrete and immersed in the ocean.

Each of these methods is costly and laborious, and when one looks at the nature of the waste materials, they all appear unnecessarily precautionary.

When the Health and Safety Laboratory was faced with the possibility of having the AEC pay the cost for the disposition of very large quantities of such material, serious consideration was given to alternative methods. The most obvious, of course, was that of handling the material as non-contaminated paper, and burning it in the open with no further control.

In order to investigate the permissibility of such a procedure a series of three experiments were set up, each one depending successively on the success of the previous one. The first experiment involved the burning of 500 pounds of material, the second was made up of about 4,000 pounds, while the third consisted of crates containing 13,500 pounds.

Method of Study

IN EACH CASE a superficial examination was made of the meteorologic conditions existing at the time in the area. An estimate was made of the height of the smoke plume in order to permit application of the diffusion equations. It was considered desirable to compare the data which were obtained from the experiments with those which might be predicted from theory.

Sampling patterns were laid out and samples were obtained on gum paper for fallout evaluation and by means of filters to determine the airborne concentration. All samples were obtained continuously throughout the experimental period. The fallout samples were collected on pressure sensitive cellophane film one square foot in area, and the air samples on 1⅛" diameter Whatman #41 filter paper at a flow rate of 15 liters per minute. All fallout samples were dry ashed and counted for beta activity on an automatic geiger tube instrument. The air samples were counted for both β and α activity, and the final ash assayed for total β and α.

TABLE I.
EXPERIMENTAL RESULTS

Item		Case I	Case II	Case III
Weight (lbs)	Original	500	4,000	13,500
	Ash	170	290	1,320
	Reduction (%)	66	93	90
Volume (ft^3)	Original	—	200	770
	Ash	—	22	75
	Reduction (%)	—	90	90
Activity (μc)	Original	780	2,000	10,000
	Ash	780	2,000	10,000
	Estimated Recovered Fallout	0.26	20	100
Fallout ($d/m/ft^2$)	Maximum	17	6,000	40,000
	Minimum	negl.	12	46
	Distance to Background (ft)	400	400	800
Air Contamination uc/ml (X 10^{-12})				
	α	1.4	—	3.2
	β	1.4	4.0	3.2

Results

IN TABLE I is shown the results of the three experimental runs. In order to evaluate the results of the test, some sort of criteria must be derived against which the results can be measured.

In general, the materials which were picked up were found to be largely mixed fission products, although small but measurable amounts of plutonium were found in some of the analyses. Presuming, however, as a limiting case that the beta activity was all strontium 90 and the alpha activity all plutonium, the following criteria would be applicable:

TABLE II.
LEVELS OF PERMISSIBLE CONCENTRATION OF RADIOACTIVE CONTAMINANTS
(From NBS Handbook 52)

Medium in which contained	Material	
	Pu^{239}	Sr^{90} / Y^{90}
Air	2×10^{-12} $\mu c/ml$	2×10^{-10} $\mu c/ml$
Soil*	5.65×10^4 $d/m/ft^2$	3.75×10^5 $d/m/ft^2$

* The value for soil assumes the same permissible concentration as in water and that the activity is all in the top 3".

In case #1 the wastes were in the form of loose boxed material so that a volume designation would be meaningless. In the other two cases the wastes had been previously tightly packed by a baling machine and had to be broken open to permit sufficient aeration for adequate incineration. Volume reductions were by a factor of 10.

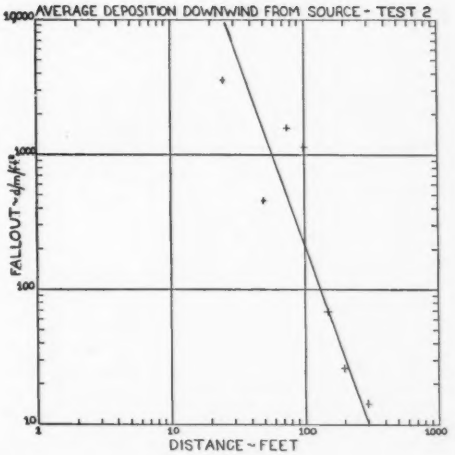

Fig. 1.

There is a certain inherent variation in the weight reductions, depending upon the amount of non-burnable materials such as laboratory glassware and bits of metal which were included in the wastes. It would be presumed that if weight reduction were a primary factor, some procedure of segregation would be employed which would reduce the non-combustibles to a minimum. In the first experiment the weight reduction was by a factor of three, whereas in both of the other cases the ash was less than 10% of the original weight.

In the first case the loss in activity was almost nil, with only 0.26 microcuries of activity computed for the fallout from an initial activity level of almost 1 millicurie. On both the second and third burning, loss of activity was negligible with a computed level of 20 microcuries in the fallout from an initial 2 millicuries quantity in the second case. The final burning of seven tons of baled material presented more anomolous results because of the conditions which prevailed during the experiment. A rough estimate based on ash measurements and other similar baled material, however, indicates approximately 10 millicuries of initial activity resulting in a fallout of approximately 100 microcuries.

The airborne activity in no case exceeded 4×10^{-12} microcuries per milliliter of either

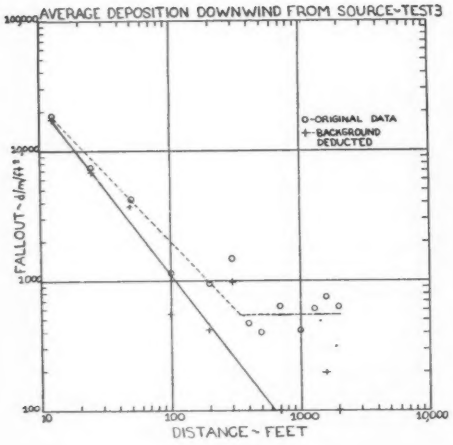

Fig. 2.

alpha or beta activity even at a distance of 25 feet.

In Fig. 1 is shown the average surface activity level plotted against radius from the pyre for the second experiment. It can be seen here that there is reasonably good agreement with the diffusion equation and that the fallout in this case probably was reduced to zero at approximately 400 feet. The maximum soil contamination even at 25 feet from the burning is far below the permissible level for either strontium or plutonium. The air activity levels are of the order of the maximum permissible level for continuous occupational exposure to plutonium. These also occurred at about 25 feet from the pyre. Beyond this radius no measurable quantity was found.

Fig. 2 presents the same information for the final experiment. Here the results are somewhat difficult of interpretation because of two extraneous factors which strongly affected the results. In the first place the experiment was carried out during a period of intermittent drizzle coupled with a highly variable wind pattern. At one time or another the wind blew from each point of the compass. In the second place the data indicate that, superimposed on the fallout from the burning, was a generalized fallout in the area. An examination of fallout records throughout the country verifies that on the day in question, levels of approximately 400 to 600 disintegrations per minute per square foot were measured from weapons test fallout activity. As can be seen from Fig. 2 a general background of approximately 550 disintegrations per minute per square foot appears to have been present in the vicinity of the testing site.

These factors make any interpretation of the data only tentative. However, maximum values can be presented. The greatest fallout level, which occurred at 10 feet, was 40,000 d/m/ft^2. This is still well below a conservative permissible level for strontium or plutonium. The air activity was somewhat lower than in the previous case. This can be explained somewhat by the presence of rain. It appears from extrapolation of the data presented in Fig. 2 that the maximum extent of measurable fallout was approximately 800 feet.

Conclusion

THE RESULTS of three experiments involving the burning of combustible materials under widely varying conditions and using greatly different quantities of waste indicates no biologically significant contamination either of the soil or of the air, created by the incineration. The quantity of material that was burned in the largest of the experimental runs is higher than would be expected to accumulate at a laboratory site in a reasonable period. If incineration of this type is carried on with a frequency dictated by the scope of operations it should be possible to consume all of the combustible waste materials in this manner, and thereby very significantly reduce the volume and weight of materials to be disposed of.

Radiation

TWENTY scientists from nine countries who met in Copenhagen August 7-11, 1956, agreed that there is insufficient knowledge of the importance and the extent of radiation effects in humans. Recommendations included improving and increasing teaching facilities, and training more scientists in genetics.

The Use of Basket Centrifugal Filters

—INDUSTRIAL HYGIENE CONSIDERATIONS

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THE INDUSTRIAL hygiene program of the American Cyanamid Company functions as a part of the Central Medical Department. A part of the program is the evaluation of health hazards inherent in the operation of chemical process equipment and the design of control measures where required.

In chemical processing, it is often necessary to perform a batch separation of solids from liquids. The basket centrifuge is widely used in the chemical industry for this purpose. The centrifuge holds a mass of material, such as a chemical slurry or crystal-water mixture, and centrifugally removes the water or other liquid from the solids. These units usually have relatively large baskets and are, therefore, operated at moderate speeds.

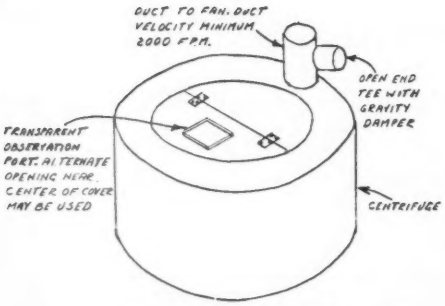
Screens of metal mesh, cloth or paper are employed to catch and hold the solids while allowing the liquids to pass through and be discharged.

The filtering operation in the centrifuge is performed in the following manner: The water-solid mixture is charged into the centrifugal basket, centrifuged, washed if necessary and spun dryed, and the solids are then unloaded from the basket and transferred to separate containers. Since a variety of potentially hazardous solids and liquids are utilized in chemical manufacture, there are many potential problems of industrial hygiene significance encountered in the use of the basket centrifuge. Some typical materials which have been processed in centrifugal filters are, aniline oil, benzene, nitrobenzene, acrylonitrile, acrylamide, mercury-bearing-solids, acids, alkalis, alcohols and other solvents. The operator may be exposed to hazardous concentrations of vapors during the charging, washing and unloading cycles when volatile liquids are processed. He may also be exposed to vapors from residual volatiles in the filtered solids during the transfer of the solids from the centrifuge to a container. In some centrifuging operations, gases entrained in the liquids are released by the centrifugal action and may constitute a health hazard by way of inhalation. In other operations, a chemical reaction may still be in process during filtration and the gases evolved also may create an inhalation hazard.

The operator may be exposed to spray, mist or wet solids during the filtration and washing cycles. Skin contact or inhalation problems of industrial hygiene significance may result from such an exposure. Skin contact with filtered solids during centrifuge unloading and the transfer to containers likewise may constitute a health hazard.

There are two general types of centrifuges used for batch filtration in chemical processing; the underdriven type and the overdriven type. The loading of an underdriven centrifuge is often done with the bowl standing still. Loading, however, is also done semi-continuously through pipe lines located in the centrifuge while the machine is in operation. This method of loading is desirable where the filtered material is fine and where uniform loading and washing is required. When this method is utilized, care must be exercised to distribute the load evenly and often necessitates continuous tending by an operator. To insure proper operation of the centrifuge, the top must be left open or partly open so that the operator can easily observe the filtration and washing. The overdriven centrifuge is usually loaded with the machine in operation.

The removal of filtered material may be performed manually by shovel or scoop from the underdriven centrifugal basket. It is also possible at times to unload an underdriven centrifuge by removing the complete


DUCT TO FAN. DUCT VELOCITY MINIMUM 2000 F.P.M.
OPEN END TEE WITH GRAVITY DAMPER
TRANSPARENT OBSERVATION PORT. ALTERNATE OPENING NEAR CENTER OF COVER MAY BE USED
CENTRIFUGE

Engineering Sketch No. 1

Typical draw-through ventilation system for the control of gas and vapor liberated during centrifuge operation. A tight cover is required as the centrifuge acts as a fan and gas may escape if cover is loose. Open end tee will insure flow inductwork at all times and minimize suction in centrifuge. An opening close to the center of the cover may be used in place of a transparent port. A control velocity of 100 F.P.M. should be maintained across the maximum working opening during centrifuge discharge.

Fig. 1.

filter cloth with the filtered material still in it. Material removal from an overdriven centrifuge is accomplished by the use of a mechanical plow or scraper and a bottom discharge opening. During the mechanical unloading the centrifuge revolves slowly.

The underdriven type of centrifuge may, in many instances, be made gas tight by the use of a hinged and gasketed cover and closed feed and discharge lines. This will prevent the escape of mist or gas from the centrifuge during filtration and washing cycles. A problem may, however, exist when the centrifuge is unloaded due to the residual vapor or gas in the filtered material. Control of residual gas or vapor may be accomplished by the use of a draw-through ventilation system. The draw-through type is especially desirable if the centrifuge is large and it is necessary for the operator to place his head close to the opening during removal of filtered product. At times the operator is required to lean over so far to remove material that his head may enter the centrifuge opening.

Engineering Sketch No. 1 shows the fundamental design for satisfactory draw-through ventilation. The sketch is self explanatory.

Fig. 1 shows the actual application of a gasketed cover and a draw-through ventilating system. The cover shown in the center foreground is equipped with a rubber gasket. The cover is tightened by the latches and knurled knobs shown. Draw-through ventilation is applied through the opening

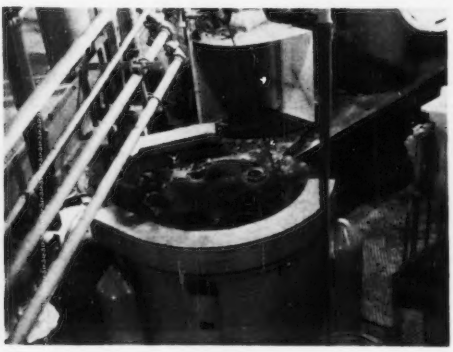


Fig. 2.

Fig. 3.

in the back of the centrifuge and the control air exhausted through the plenum chamber and the flexible ductwork as shown in the right rear of the picture. The switch in the right foreground automatically causes the mechanical exhaust system to operate when the hinged cover is opened. A control velocity of 100 F. P. M. is maintained through the opening.

Slot type ventilation may also be utilized for control purposes on the underdriven centrifuge but is only recommended where solids removal may easily be accomplished from outside of the centrifuge.

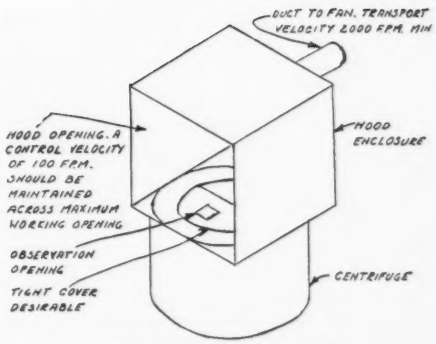
Figs. 2 and 3 show typical applications of slot ventilation for control of vapors and gases from an underdriven centrifuge. The air is drawn laterally into the slots and, therefore, would not provide satisfactory control if the operator found it necessary to insert his head into the centrifuge. The control volume requirements are those of standard type slot ventilation. A hooded enclosure may also be employed, but the same qualifications should be kept in mind as in the case of the slot hood. It is often desirable to observe the flow of slurry into the centrifuge to prevent overloading and to insure an even distribution of solids. It is often possible to accomplish this by the provision of a glass or clear plastic cover in the top of the centrifuge. Some slurries, however, tend to cloud the transparent covers. In such cases, an opening located close to the center of the centrifuge cover may be used as an observation port. Draw-through, slot or hood enclosure may be used for vapor control during centrifuge unloading if necessary.

It is difficult to maintain a tight cover on an overdriven centrifuge. Openings are required for the shaft and for the mechanical scraper which is usually used in conjunction with an overdriven centrifuge. Satisfactory control of gas and vapor has been realized by enclosing the top opening as much as is feasible and using local exhaust ventilation in the form of a hood enclosure with the front open. A tight seal is required at the front top cover of the centrifuge.

Engineering Sketch No. 2 shows the design details of a hooded enclosure for a centrifuge. Fig. 4 shows an actual installation of this type.

The front portion of the centrifuge opening is covered and process observation is made through the rear portion of the opening. This partial cover prevents gases at high velocity from escaping from the front of the centrifuge and allows the mechanical exhaust system to satisfactorily control vapor emissions. During the solids removal, the cover is removed. A control velocity of 100 F. P. M. is maintained across the opening of the hooded enclosure over the centrifuge.

The centrifugal filter, when operated with the top open and at high speed, acts like a fan and pumps a considerable air volume.


DUCT TO FAN. TRANSPORT VELOCITY 2000 FPM. MIN.
HOOD ENCLOSURE
HOOD OPENING. A CONTROL VELOCITY OF 100 F.P.M. SHOULD BE MAINTAINED ACROSS MAXIMUM WORKING OPENING
OBSERVATION OPENING
TIGHT COVER DESIRABLE
CENTRIFUGE

Engineering Sketch No. 2

Hood enclosure for control of gas or vapor liberated during centrifuge operation. Observation opening should be located close to the center of the cover. A tight cover is desirable. A control velocity of 100 F.P.M. should be maintained across the maximum working opening.

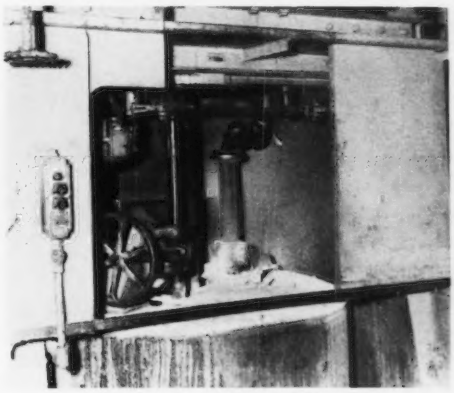
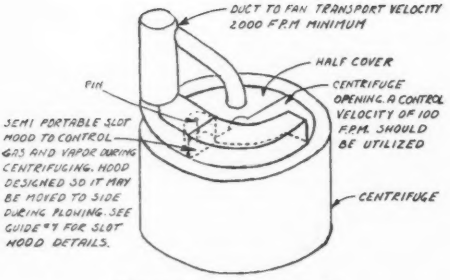


Fig. 4.


DUCT TO FAN TRANSPORT VELOCITY 2000 F.P.M. MINIMUM
HALF COVER
PIN
CENTRIFUGE OPENING. A CONTROL VELOCITY OF 100 F.P.M. SHOULD BE UTILIZED
SEMI PORTABLE SLOT HOOD TO CONTROL GAS AND VAPOR DURING CENTRIFUGING. HOOD DESIGNED SO IT MAY BE MOVED TO SIDE DURING PLOWING. SEE GUIDE #7 FOR SLOT HOOD DETAILS.
CENTRIFUGE

Engineering Sketch No. 3

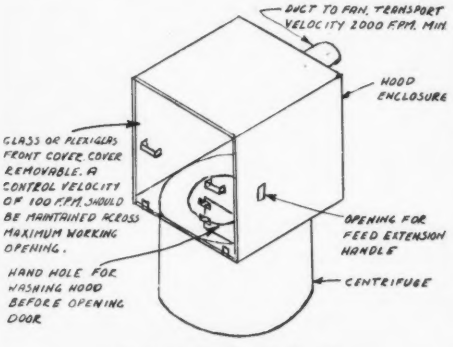
Combination slot type and draw through ventilation system to control gas and vapor liberated during centrifuge operation. Slot hood controls gas and vapor during centrifuging and is moved aside when plowing is carried on. Draw through ventilation provides control during plowing. A control velocity of 100 F.P.M. should be maintained across the maximum working opening of the centrifuge for draw through ventilation, approximately 1000 C.F.M. should be utilized for the slot ventilation.

Fig. 5.

Fig. 6.

A study of the pattern of the air in motion from a centrifuge in one of our plants resulted in the hood design shown in Engineering Sketch No. 3 and in Figs. 5 and 6. The slot shown in the photograph acts similar to the scroll on a fan and the air pumped by the fan action of the centrifuge is directed to the duct and is mechanically exhausted. The slot is swung out of the way when the centrifuge is unloaded. The slot is shown in both the open and closed positions in Fig. No. 5. Draw-through ventilation is used for control during the unloading phase of the operation. The back half of the centrifuge is covered and is exhausted through the duct which can be seen at the center rear of Fig. 6. An empirical volume of 1000 C.F.M. was used in this design. This volume satisfactorily controlled vapor evolved during the centrifuging operation. A control velocity of 100 F.P.M. was maintained through the centrifuge opening for control during unloading.

In operations where absorption of toxic materials through skin contact as well as by inhalation present a problem, a complete enclosure of the centrifuge may be necessary to minimize possibility of contact through spray and mist. Engineering Sketch No. 4 shows the fundamental design requirements


DUCT TO FAN, TRANSPORT VELOCITY 2000 FPM. MIN
HOOD ENCLOSURE
GLASS OR PLEXIGLAS FRONT COVER. COVER REMOVABLE. A CONTROL VELOCITY OF 100 F.P.M. SHOULD BE MAINTAINED ACROSS MAXIMUM WORKING OPENING.
OPENING FOR FEED EXTENSION HANDLE
HAND HOLE FOR WASHING HOOD BEFORE OPENING DOOR
CENTRIFUGE

Engineering Sketch No. 4

Hood enclosure for control of materials which present a health hazard through skin contact as well as inhalation. Transparent door protects operator from spray or splash. Small hand hole permits washing of equipment with protection against spray. An opening to suit conditions is provided for feed valve extension handle. A control velocity of 100 F.P.M. should be maintained across the maximum hood working opening.

Fig. 7.

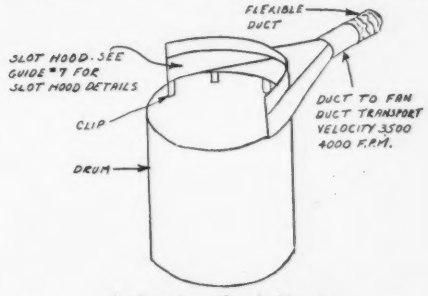
for a completely enclosed centrifuge. Fig. 7 shows a complete enclosure. The plastic front cover, easily removed, is utilized in order that the operation may be observed easily. Feed and washing operations are performed remotely by extending valve handles through the enclosure. The handle may be seen on the right of the enclosure. A partial opening may be installed if it is desirable to wash the equipment before solids removal. As shown in the photograph, the front door on this installation is made in four parts, any of which may be opened for washing of the equipment. The front door is easily removed. In this installation the front door lifts out after the latches on the top frame have been opened. Local exhaust ventilation is provided in case of vapor exposure during solids removal. A control velocity of 100 F.P.M. is maintained across the opening with the door removed.

Some suppliers of overdriven centrifuges provide units complete with liquid seals and hooded enclosures for use in operations where toxic or flammable materials are handled.

Operators may also be exposed to vapor during transfer of product to containers. If the transfer is made to a drum by scoop or shovel, a simple slot hood will provide excellent control. The slot is located above the top lip of the drum. Engineering Sketch No. 5 shows the design details of a slot type hood for the control of gas or vapor evolved during the transfer of wet solids from the centrifuge to a container. If discharged mechanically through a bottom opening into drums, tote boxes, etc., an enclosure of the container with mechanical exhaust will provide the necessary control. Engineering Sketch No. 6 shows the design details of a mechanically exhausted enclosure to control gas and vapor during the unloading of an overdriven centrifuge.

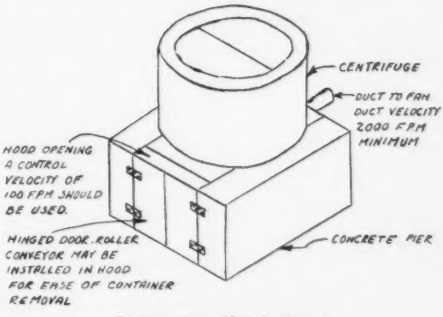
Fig. 8 shows an enclosure of the discharge of a centrifuge by a complete boxing of the foundations. In this photograph the doors are closed, which is the case during the centrifuging cycle. This machine operated with an open bottom and the enclosure made it possible to contain and control vapors evolved through the open bottom. Mechanical exhaust ventilation of 100 F.P.M. through the hood opening was employed.

On the right of the photograph is shown



Engineering Sketch No. 5

Slot type ventilation for control of dust liberated during scooping and shovelling of solid material from drums. A control velocity of 125-200 F.P.M. is required. Hood is portable for ease of handling.


CENTRIFUGE
DUCT TO FAN DUCT VELOCITY 2000 F.P.M MINIMUM
HOOD OPENING A CONTROL VELOCITY OF 100 F.P.M. SHOULD BE USED.
HINGED DOOR. ROLLER CONVEYOR MAY BE INSTALLED IN HOOD FOR EASE OF CONTAINER REMOVAL
CONCRETE PIER

Engineering Sketch No. 6

Hood enclosure for control of gas and vapor liberated during centrifuge discharge. Hood as shown utilizes concrete support piers as part of hood. Drum filling hood (Guide #8) or tote box loading hood (Guide #32) may also be used. A control velocity of 100 F.P.M. should be maintained across the hood opening.

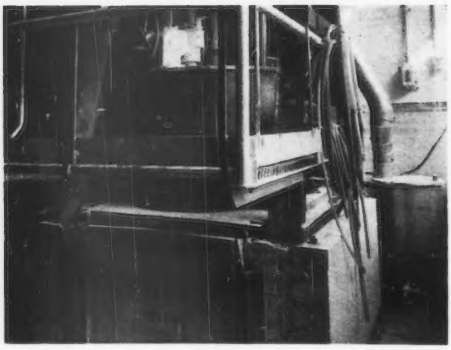


Fig. 8.

a liquid receiver which contains the filtrate from the filtration process. This is shown mechanically exhausted for control of vapor. When the filtered material or the residual liquid in the filter cake may constitute a health hazard by way of skin contact, the operator is furnished with rubber gloves and other protective clothing which the particular operation dictates.

Summary

THE ENGINEERING SKETCHES described and illustrated herein are a part of a guide manual which is furnished to the managers and engineers in the various company plants by the Central Medical Department. Details of hoods and mechanical exhaust ventilation for various process equipment, as well as centrifuges, are outlined in the manual for use in the design of control measures for existing problems or for potential problems in new plants or processes.

Existing installations have shown that it is possible to handle highly toxic raw materials, intermediates, or finished products without serious exposure to workmen. The control installations are designed to operate without significant loss of product or production time.

The practice of Cyanamid's Industrial Hygiene Section is to include hoods and mechanical exhaust ventilation for centrifuges and other process equipment where needed on the flow sheets of new or changed processes.

Renewal Reminder

A LARGE percentage of the subscriptions to the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION QUARTERLY are on a calendar year basis. These subscriptions expire with the December issue. Renewal notices are being sent to non-members now. To assure continuous delivery of the QUARTERLY for 1957, readers are asked to renew at an early date.

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CONSULTATION and RESEARCH

AIR POLLUTION
INDUSTRIAL HYGIENE
AND
TOXICOLOGY

TRACE ELEMENT
ANALYSES
AND
MICROCHEMICAL

Pulmonary Radiation Effects

as a function of absorbed energy distribution

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Department of Occupational Health
Graduate School of Public Health, University of Pittsburgh

IN THE CASE of many internally deposited radioactive isotopes, sufficient information regarding the critical organ and the response of that organ to radiation is known. Using this biological knowledge as a basis, it is possible to calculate environmental contamination levels that would result in radiation exposures below the damage threshold.[1,2,3] In the case of inhaled, insoluble radioactive particles, however, the exact nature of the dose effect relationship, qualitatively as well as quantitatively, is not known for pulmonary tissue. A frequently used semi-quantitative description of the interaction between radiation and the lung is the appellation "radio-resistant" that is applied to the lung.[4]

Qualitatively, the lung damage to man resulting from therapeutic x-ray doses is said to consist mainly of pneumonitis that is histologically indistinguishable from chemical or influenza pneumonitis.[5] The difficulty in attempting to quantitate the pulmonary dose effect relationship in the case of inhaled insoluble radioactive particles is further aggravated by the non-uniform absorption of energy from a focal radiation source. If a single beta emitting particle embedded in the pulmonary parenchyma is considered, then it can be shown that the absorbed dose depends very strongly on the distance from the radioactive particle, and that the absorbed dose close to the particle will be very high.[6] In the case of a 9×10^{-4} microcurie $BaS^{35}O_4$ particle, for example, the dose rate at a distance of five microns is 94,000 rep/day. At 50 microns, the absorbed dose rate is down to 1400 rep/day. The very intense absorbed dose close to the inhaled particle raised a number of questions regarding the radiological hazard from contaminated atmospheres and the parameters necessary to describe the degree of hazard.[7,8]

In an attempt to answer some of these questions, an experiment was performed in which rats were exposed by inhalation and by intratracheal insufflation to radioactive barium sulfate particles in doses ranging from 4.5 microcuries to 4.5 millicuries of sulfur 35. The absorbed dose from the acute insufflation of 4.5 millicuries, as determined from the time integral of the daily dose rate over a nine month period, was 24,000 rep.[9] In calculating the value for the absorbed dose, account was not taken of the focal nature of the radiation or of the heterogeneous distribution of the radioactive particulates within the pulmonary tree.

Accordingly, it was assumed that all the energy from the beta radiation was uniformly absorbed by the lung tissue. That this assumption is not valid may be seen

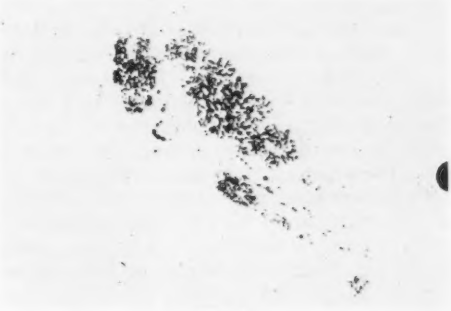

Fig. 1.
Autoradiograph from lung section of a rat sacrificed immediately after $BaSO_4$ insufflation, 10X.

Based on a talk given at the annual meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION in Philadelphia, April 26, 1956.

This work was performed under AEC Contract AT-(30-1).

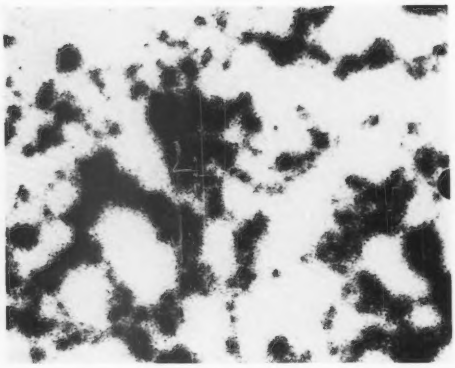

Fig. 2.
Autoradiograph from lung section of a rat sacrificed immediately after $BaSO_4$ insufflation, 250X.

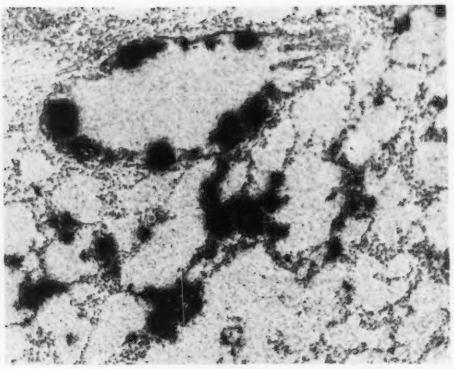

Fig. 3.
Autoradiograph from lung section of a rat sacrificed four days after $BaSO_4$ insufflation, 250X.

from Figs. 1 and 2 which are autoradiographs of lung sections from animals sacrificed immediately after exposure. The non-uniformity of exposure was further increased as the particles were eliminated from the lungs, as shown by Fig. 3, an autoradiograph of a lung section from an animal sacrificed four days after exposure. Because of the focal nature of the radiation sources and the very short range in tissue of the low energy beta particles, it can be seen from the autoradiographs that only a fraction of the total lung tissue was intensely irradiated. Obviously, many irradiated portions of the lung must exceed 24,000 rep in order to achieve this mean value. In spite of the high doses no serious pathology that could definitely be attributed to radiation was observed during a nine month interval following exposure.

The apparent absence of serious pulmonary damage was thought to be related to the observed non-uniformity of dosage and the consequent low dose delivered to a fraction of the lung. This explanation of the unexpected results is not incompatible with a reported experiment in which one group of rats were exposed to beta rays from strontium 90 yttrium 90 by uniformly spreading the radioactive material over a large area of the skin; and another group of rats were exposed to the same quantity of activity but differing from the first in the method of application. In the latter group the strontium 90 yttrium 90 was concentrated in a number of point sources that were topically applied. The investigators found that "malignant and benign tumor formation was greater after exposure to diffusely distributed beta radiations than after exposure to the same amount of isotope in point sources, suggesting that exposure to hot particulate matter does not entail an unusual hazard due to spatial concentration of radioactivity."[10] It was decided to test the application of this hypothesis to the case of inhaled radioactive particulates by exposing rats to x-rays delivered to the thoracic region only and administered through several portals. In this manner, it was possible to give the lungs a more uniform absorbed radiation dose than would be delivered by an acute dose of radioactive barium sulfate particles.

Experimental Technique

FEMALE rats of the Carworth Farms Wister strain whose average weight was 270 grams were used in this experiment. The x-rays were generated in a Westinghouse therapeutic x-ray tube operated at 100 KV and 4 milliamps, Fig. 4. A 1 mm aluminum filter hardened the beam to an effective wave length of 0.46 angstrom units. Two groups of 20 rats were exposed to air doses of 5,750 and 11,500 r respectively; a third group of 15 rats received an air dose of 17,250 roentgens. Twenty rats were kept as controls. The total dose in each case was fractionated into five equal parts, de-

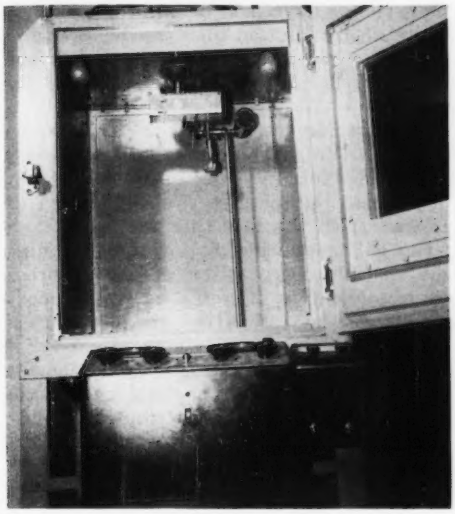

Fig. 4.
X-ray exposure apparatus.

livered at daily intervals at a rate of 61.8 r per minute in air. Exposure of the thoracic region only was accomplished by means of a lead cone with a 2 cm diameter orifice that was placed directly on the chest, and a specially designed lead shielded aluminum box for holding the rats during irradiation. To achieve more uniform lung irradiation, each daily exposure was subdivided into four parts, delivered through different portals. The target to skin distance was 16 cm. Under these exposure conditions, and assuming that the lungs are overlaid by 5 mm tissue and are 1½ cm thick, the integral dose for each exposure group is 22,800, 14,850, and 7,850 gram roentgens. If a mean pulmonary weight of 1.5 grams is used,[11] these integral doses correspond to 14,800, 9,900, and 4,900 rep respectively. A 25 r Victoreen thimble chamber was placed in the rat holder alongside the animal during exposure. The instrument reading after every exposure was much less than 1 r, thereby showing that the total body irradiation was insignificant compared to the dose absorbed by the lungs. After irradiation the rats were kept in cages containing two animals each and were permitted to eat and drink *ad libitum*. When a death occurred, the rat was autopsied and the vital organs were removed for histological examination.

Results

A RELATIVELY high lethal effect was observed in all the treated animals, with the mortality rate correlated to the dose. Fig. 5 shows the distribution of deaths with respect to time after exposure. In the highest dose group, a latent period of three weeks passed before any animals died. After this latent period, the highest death rate was observed, with ⅔ of the group dying between the third and sixth weeks. The balance of the rats in this group died during the next 16 weeks.

In the case of the 11,500 r group too, a three week period elapsed before the first death was observed. At this lower dose, however, the death rate remained approximately constant throughout the following 10 month period at the end of which time the last rats in this group died.

For the 5,750 r group a much longer latent period was observed. Although the first death occurred six weeks after exposure, no more animals died until six months after irradiation. Thereafter, the death rate was approximately linear with time. Fifteen months after exposure six surviv-

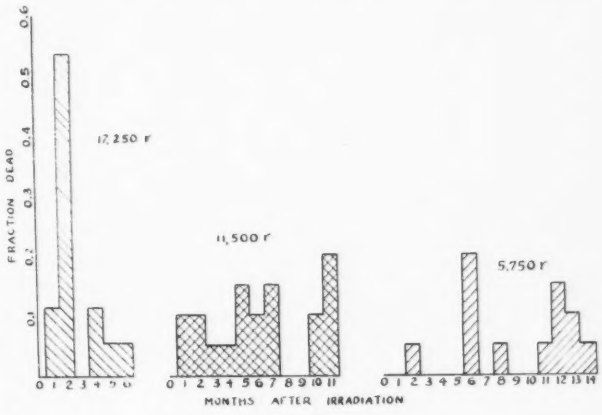

Fig. 5.
X-ray mortality distribution.

ing rats from this group were sacrificed.

The lethal effects of the three x-ray doses could be summarized by giving the median lethal time for death. For the 17,250, 11,500, and 5,750 r groups, the median lethal times were 37 days, 166 days, and 12 months, respectively. During all this time no losses were incurred in the control rats. Histologic examination of the tissue sections showed that severe pathologic changes predominated in the lungs. The most frequently observed condition was broncho-pneumonia. Two rats from the lowest dose group and one from each of the other groups had massive pulmonary lymphomas. Although the malignancies were principally in the lung, metastases were also found in the liver, spleen and the spine. This multiplicity of tumor sites makes it impossible to be certain of the primary location of the tumor.

Discussion

THE DRAMATIC results of the external pulmonary irradiation indicates the validity of the hypothesis that a spatial concentration of absorbed energy may be less hazardous than a more uniform distribution of the same total amount of absorbed energy in a greater volume of tissue. This suggests that a critical relationship exists between total energy absorbed and the energy distribution in the absorbing tissue. If this is true, then the tolerance value for atmospheric particulate contamination is overestimated on the safe side, since calculated values are based on homogeneous energy absorption in the lung.

Although all the parameters that govern the degree of radiological hazard from beta emitting radioactive dusts are not yet known, our experiments suggest that the energy of the beta rays may be of great significance. This clearly follows if the critical volume hypothesis is valid. Of equal importance would be the size distribution of the dust particles. It should be emphasized that this size distribution dependence is in addition to the relationship between particle size and pulmonary retention. For any given amount of activity, the number of particles, and therefore the number of foci of radiation, varies inversely with the cube of the particulate diameter. A large number of diffusely distributed dust particles that emit high energy beta rays will, therefore, more closely approach the limiting condition of uniform radiation than the deposition of a smaller number of large particles, and may consequently be more toxic than the latter.

The specific activity of the particles, according to this hypothesis, is of secondary importance for any given amount of activity or for any given energy absorption. This follows from the fact that the specific activity will be the chief factor in determining the spatial concentration of the absorbed energy, and this, it seems, is of secondary importance in estimating the radiological hazard from inhaled particles. A quantitative relationship between biological damage on the one hand and the total energy absorbed and its spatial distribution in the lung, on the other hand, is still to be experimentally determined.

Acknowledgments

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THE GENERATION OF
A Solid Sub-Micron Test Aerosol

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A SOLID PARTICLE generator has been devised for use as a standard test instrument in connection with measuring the dust retention of filter media. The generator possesses several characteristics which are desirable for this application such as very small solid particles, reproducible concentration, reproducible and selectable size spectra, sustained generation, and the aerosol which is formed lends itself to easy measurement in minute quantity. The generator unit is simple and sufficiently compact so that it may be shelved conveniently when not in service. Uranium fume, the generated aerosol, is representative of one of the more difficult-to-collect kinds of contaminants found in the industrial plants serviced by this laboratory and as such provides a severe but realistic filter test.

Uranium fume, U_3O_8, has been used by others[1,2] to check the performance of filter media. In these applications, the fume was generated by passing metered air through a fixed bed of metal chips. This type of generator was tried in this laboratory before the moving bed device was developed. The chips were burned in a one-inch tube through which air was passed. In preparing the generator for burning, the chips were deposited along a wire mesh strip one inch wide which was then inserted horizontally in the tube. Chips were ignited at one end of the strip and then allowed to burn in a chain-like fashion along the strip. The burning was self sustained but extremely erratic, that is, the burning would accelerate or retard along the strip in an unpredictable manner. The resultant fume varied substantially in concentration and particle size from one run to another. After several runs were made using air to support combustion, a metered mixture of argon and oxygen was substituted to provide some measure of control over the rate of burning. Although by this system the net rate of burning could be increased or decreased, the brief but significant fluctuations in any run were not eliminated.

The moving bed principle was conceived as a method of achieving better control of burning. It was conjectured that if a fairly narrow gas stream was passed perpendicularly through a bed of chips moving at a slow rate past the stream, the rate of burning advance could be made more uniform by proper adjustment of the speed of motion and the burning could be confined approximately to the small cross section of the gas stream. The device shown in Figs. 1 and 2 was fabricated to study this principle. In this unit, the uranium chips are supported on a ½-inch-wide circular trough of 16-

An aerosol generator has been devised which produces a uranium fume of controllable concentration and reproducible size spectrum for a sustained period. The fume is emitted from uranium chips burned in an argon and oxygen gas stream. To achieve uniformity in burning, new metal surfaces are continuously presented by slowly moving the chips through the gas stream on a wire mesh bed rotated by a slow-speed motor. It has been demonstrated that the median particle size can be pre-selected for any given run over the range of 0.05 μ ($\sigma_g = 2.5$) to 0.2 μ ($\sigma_g = 3.1$) by establishing the appropriate argon to oxygen ratio and total gas flow-rate. The unit serves as a standard test-aerosol generator for filter efficiency measurement.

Fig. 1.
Fume generator with cover open for charging.

mesh stainless steel screen mounted peripherally on an aluminum turntable, nine inches in diameter. This is rotated by a d.c. timing motor. The trough and turntable assembly is enclosed in a circular aluminum, lucite, and transite container with a hinged cover. In use, the container is sealed tight except for the gas stream inlet and outlet ports. The inlet is a vertical 3/8" i.d. copper tube which pierces the container base and terminates within 3/16" of the bottom of the wire trough. The outlet is an inverted pyrex funnel sealed to a three-inch-diameter circular hole in the container cover concentric with the inlet tube. The turntable rotates at about 1/6 RPM. The timing motor is mounted below, external to the turntable case.

To charge the generator, the cover is opened and uranium chips, prewashed with CCl_4, air dried, and screened to reject fines, are deposited on the wire mesh bed. The loading per unit length of circumference is made reasonably uniform. The uranium metal (we have used 1/8" wide machining chips) is placed in a single layer on the mesh. Ignition is begun by means of a nichrome wire filament heated by a variable voltage transformer. Argon and oxygen

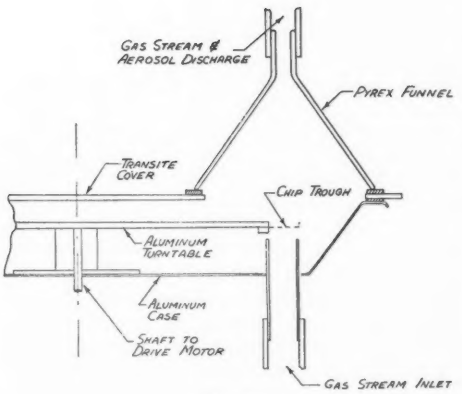

Fig. 2.
Partial cross section of fume generator.

tanks, connected through flowrators to the gas inlet tube, supply the gas stream which supports combustion.

Within certain limits of argon to oxygen ratio and turntable speed, the burning is localized to an area about a half inch in diameter just above the gas inlet tube. The vigorousness of the burning, as would be expected, is a function of the gas ratio. Combustion can be sustained up to an argon to oxygen ratio of 3.67:1. Below a ratio of 1.8:1, the burning is so vigorous that the resultant heat melts the caulking material on the casing.

Initial particle size measurements of the generated aerosol indicated a possibility that size might be a function of gas ratio and/or total gas flow rate. It was determined that uniform burning rates could be maintained at volume rates of from seven to 21 liters per minute over the range of gas ratios mentioned above.

In order to establish the significance of gas ratio and volume on particle size, test sequences were conducted based on a Greco-Latin Square plan. Three different ratios of argon to oxygen were selected as well as three gas volume rates. The ratios were 1.8:1, 2.5:1, and 3.67:1; the volume rates were 7, 14, and 21 liters per minute. Three tests were made, of nine runs each.

Sampling Procedure

DURING the evaluation of the equipment, the fume emitted from the generator was directed through a tube into a plastic

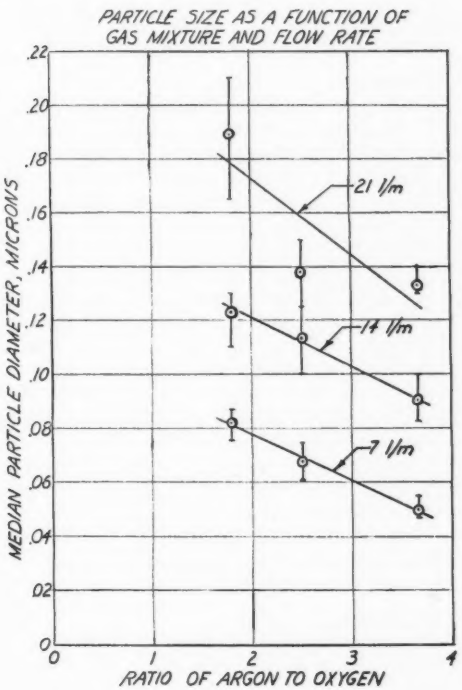

Fig. 3.

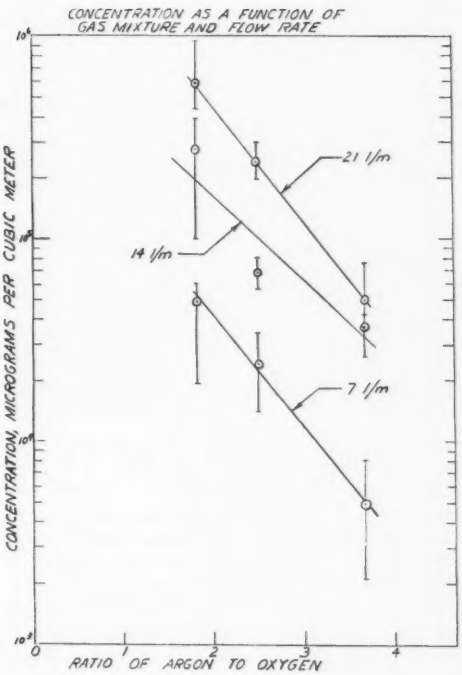

Fig. 4.

cylinder three inches in diameter by twelve inches long, which served as a sampling manifold. Samples for particle size measurement were collected with a Casella thermal precipitator inserted in the side of the cylinder. Formvar coated, electron microscope grids were mounted on the precipitator plugs. The grids were electron-photomicrographed for particle size determination. Fume concentrations were measured from samples collected on a molecular filter in a holder attached to the downstream end of the sampling manifold. This filter collected all of the fume generated (less the 7 cc/min which went to the thermal precipitator) in each run. Uranium content was measured by fluormetric analysis. A molecular filter sample and a thermal precipitator sample were collected for each of 27 calibrating test runs.

Experimental Results

PARTICLE SIZE and concentration were found to be functions of both the gas volume rate and the gas ratio. Analysis of variance for the data revealed:

1. A highly significant linear relation of particle size to ratio and volume (rate) over the range of variables investigated.

2. A highly significant relation of concentration to ratio and volume over the range of variables investigated.

3. No significant relation between time and either particle size or concentration.

4. After correcting "particle size" for "time" and "concentration" by the method of multiple covariance, the relation of particle size to ratio and volume remained highly significant over the ranges investigated.

Figs. 3 and 4 show, respectively, the relation of particle size to ratio and volume and the relation of concentration to ratio and volume. It will be observed that the average particle size increases progressively in steps from the lowest value of 0.05 μ at a ratio of 3.67:1 and a volume rate of 7 1/m to 0.2 μ at a ratio of 1.8:1 and a volume rate of 21 1/m. One may observe that the concentra-

Fig. 5.
Electron photomicrograph of uranium fume shadowed with chromium.

tions increase in a somewhat similar pattern with this exception: there is considerable overlap of concentrations over portions of the three volume rate curves but no corresponding overlapping of particle sizes. This would indicate that the change in particle size with gas flow conditions is not a reflection of changing concentrations, leading to greater agglomeration at the higher concentrations.

Fig. 5 is typical of the electron-photomicrographs used for size measurement.

Summary

A MOVING bed aerosol generator has been made and tested which produces a uranium fume. The fume was demonstrated to possess the following characteristics: (1) reproducible size spectra and concentration, (2) preselectable size median over the range of .05 μ to 0.2 μ, (3) sustained generation up to six minutes. The duration of the generating period is limited only by the circumference of the moving bed; a larger diameter turntable would permit a proportionately longer generation period.

The rate of aerosol emission during the period of generation is essentially uniform when the turntable speed is adjusted to a constant rate equal to the rate of burning advance for the particular gas ratio and volume used.

The characteristics of the generated aerosol are suited for application as a filter retention test medium.

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Interstate Sanitation Commission

THE INTERSTATE Sanitation Commission has launched an interstate study of smoke and air pollution in New York and New Jersey. The director and chief engineer of the ISC announced that FREDERICK MALLETTE has been named technical consultant for the study. The ISC is empowered "to make a comprehensive study of smoke and air pollution in the areas of New York and New Jersey specified . . . . and the problems caused thereby. The study shall include a survey of the sources and extent of such pollution, property damage caused thereby, its effect upon public health and comfort, and relevant meteorological, climatological, and topographical factors." The final report by the commission will set forth its findings, its recommendations for a smoke and air-pollution control program, and a plan for the administration of such a program by an appropriate agency. Also to be included is a study and evaluation of existing laws relating to air pollution and drafts of proposed legislation to carry out the recommendations of the commission.

Radon and Radon Daughter Hazards in Mine Atmospheres

—INVESTIGATIONS ON SUPPLEMENTAL CONTROL

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THE STUDY of the health hazards associated with the mining and milling of uranium ore has shown that, while all the members of the uranium family are present in the ores, the internal radiation hazard of greatest concern is that associated with radon and its immediate degradation products.[1-4]

Additional work,[5,6] has shown that the hazard from the radon daughters is greater, by far, than from the parent. These findings and the exceedingly high levels of radon and its degradation products extant in many mines led to the conclusion that the problem of immediate importance was to develop methods for reducing the atmospheric concentrations of these elements.

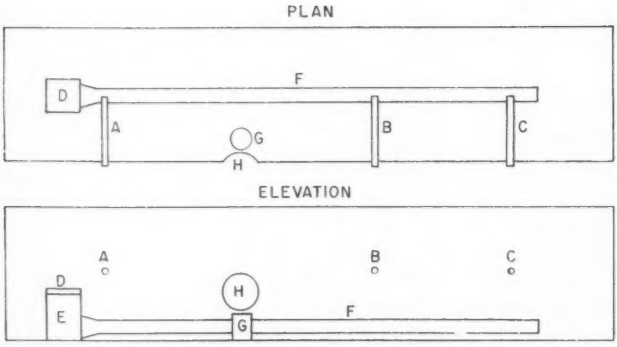
The control of radon and its daughters by dilution ventilation has been reported.[7] Supplemental control of this internal hazard may be approached in two ways. The daughters themselves may be removed or the radon, the source of the daughters, may be reduced. Results of laboratory studies of these two methods are reported here.

Experimental Chamber

IN ORDER to simulate mine conditions, a gas chamber was constructed inside a building in the shape of a mine drift with interior dimensions of approximately 7¾′ x 7¾′ x 36′ with a corresponding volume of 2,135 cubic feet. The floor of the chamber was ¼-inch plywood tacked to the floor of the building, over which was cemented a high gloss plastic linoleum. This, in turn, was sealed to the walls by quarter-round moulding, tacked and cemented in place. The walls and ceiling of the room were of standard ½-inch sheet-rock construction except for four plywood panels on one side. Joints were taped and sealed. Access doors at each end were made of single ¾-inch plywood panels and were held against a gasketed framework by crossbars. Vapor-proof lights were installed in the ceiling and the interior was covered with three coats of gloss white enamel to minimize diffusion of radon through the walls.

Observation windows, sampling ports, and ports for the remote control of instruments were placed in the side plywood panels. Two-inch pipes, extending from the centerline of the interior to the outside of the chamber, were located at each end and in the center of the side wall. These pipes were sufficiently large to permit the passage of filter paper holders so that daughter product samples could be taken directly within the room with no danger of having them plate out on the walls of a sampling tube. A diagram is shown in Fig. 1.

Gas losses from the chamber were determined by noting the decrease in the radon content over a period of six days. The observed decrease in radon concentration with time is compared with the expected decrease due to radioactive decay in Fig. 2. It can be seen that the loss of radon from the chamber is approximately 4% per day. As all individual experimental runs were of less than 24 hours' duration, no corrections were made for leakage from the chamber.



EXPERIMENTAL CHAMBER - SCHEMATIC

A,B,C - Sampling Ports
D - Filter Unit
E - Blower Plenum
F - 8" Duct
G - Deemanation Flask
H - Observation Bubble

Fig. 1.

Radon Removal

RADON, being an inert gas, is most amenable to adsorption as a means of removal. A review of the literature on adsorption indicated that both silica-gel and zinc-activated coconut charcoal had been successfully used in adsorbing radon, and the respective isotherms for these products were determined.[8,9] More recent work[10] pointed to the use of molecular sieves* for the adsorption of other noble gases. Preliminary calculations indicated that silica-gel would be impractical for the use to which a required adsorbent would be put in a mine situation. Experimental work therefore was limited to the latter two adsorbents.

Two sources of radon were used. The first was from the decay of the radium associated with high-grade uranium ore sealed in a 141-liter box. The second source was from a 7.5-millicurie sulfate-free radium bromide solution contained in a deemanation flask. Radon deemanated from the solution was introduced into a 60,000-liter room, a complete description of which has been given in the previous section.

Radon concentrations were determined either by the ionization chamber-vibrating reed electroscope method developed by the New York Operations Office of the AEC or by the scintillation chamber method of Van Dilla.[11]

*Calcium & sodium alumino-silicates.

The adsorbent was packed in a five-centimeter diameter glass tube to a depth of 10 centimeters. Radon-laden air was drawn through the bed at a rate of one liter per minute. Upstream and downstream samples were taken at the inlet and outlet of the adsorbing column. Glass-wool filter plugs inserted in the sampling lines prevented existing radon daughters from entering the sampling flasks.

All runs were made until the downstream concentration equaled the upstream concentration. At this point the adsorbent was deemed to be exhausted, the run stopped, and the total amount adsorbed was calculated. Runs were made at varying concentrations ranging from 2,000 to 80,000 micromicrocuries per liter. The total adsorptive capacity per gram of adsorbent for each concentration was determined. The adsorptive capacities of the zinc-activated coconut charcoal and the 5A molecular sieve (calcium alumino-silicate) under the conditions noted are presented in Fig. 3. The adsorptive capacity of the 4A molecular sieve (sodium alumino-silicate) for radon was too low to be of any significance.

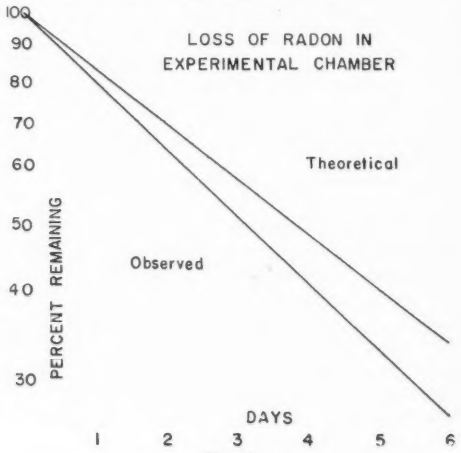


Fig. 2.

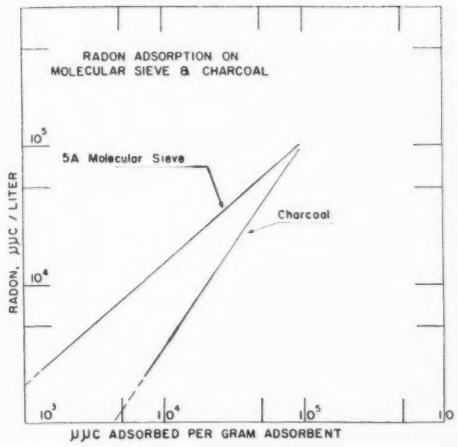


Fig. 3.

From Fig. 3, the amount of charcoal or molecular sieve needed to remove the radon in a given mine area can be calculated. For example, in a dead-end drift measuring 8′ x 8′ x 30′ with a radon emanation rate of 2 x 10^{10} atoms per minute (typical of many mines in the Colorado Plateau), there would emanate into the area 21 micromicrocuries of radon per liter per minute. In order to keep the radon level in that drift at 1,000 micromicrocuries per liter for a 24-hour period, 825 pounds of zinc-activated charcoal or 7,200 pounds of 5A molecular sieve would be needed. Even considering the possibility of regenerating the adsorbent, the studies indicate that the use of adsorption techniques as a means of reducing radon concentrations in mine atmospheres does not appear to be practical.

Radon Daughter Reduction

IN ORDER to evaluate the feasibility of filtration as a means of removing radon daughters from the atmosphere, a package unit was designed and built. A blower with a rated capacity of 600 cfm at 1¾″ of water was mounted in a 2′ x 2′ x 3′ plenum. The plenum entrance was designed to accommodate 20-inch or 24-inch filters. The blower discharge was connected by suitable transition to 27 feet of eight-inch diameter galvanized duct. This unit was placed in the experimental chamber with provisions for controlling and measuring flow from outside the chamber.

The unit was operated in a fixed radon concentration for most of the test runs. Samples taken at the port near the unit intake were used as an index of the chamber concentration. Operation was continued until the concentration index remained constant, when it was assumed that a steady state had been reached. Absolute filter removal characteristics were evaluated by taking downstream samples within the plenum. This, however, necessitated entering the room after a radon concentration had been established and did not lend itself to steady-state evaluation.

Radon samples were taken and analyzed as previously described. Daughter samples were collected at the centerline of the chamber on one-inch diameter type AA membrane filters and were analyzed in one of two ways. The more detailed method required the construction and analysis of a decay curve of alpha activity according to Tsivoglou[12] whereby the absolute amounts of the RaA, RaB, and RaC could be determined. The second method, by which most of the radon daughter samples were analyzed, consisted of the determination of alpha activity at a measured time after sampling with conversion back to sampling time and atmospheric concentration. Except for a few low-level samples, all samples were taken as two-liter grab samples.

An important characteristic of the im-

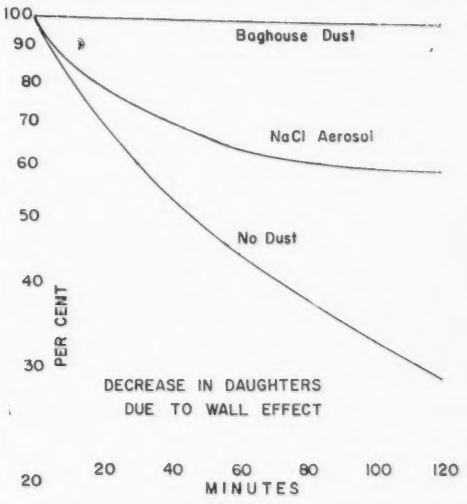


Fig. 4.

mediate daughters of radon is their particulate nature and consequent tendency to plate out on available surface area. This "wall effect" was evaluated by circulating three test aerosols at 1,060 cfm with results as shown in Fig. 4. Settled room air was used for the "no dust" condition. The "baghouse dust" was obtained from the air cleaning unit of an ore assaying and analyzing facility. This dust was suspended by air jet. Initial concentrations ranged up to 40 mppcf, with a median particle size of 1.5 microns. It was noted that light field counts of baghouse dust concentrations could be reduced by over 90% with only a 30% reduction in the air-borne radon daughters.

In order to determine what portion of the observed daughter reduction was caused by "wall effect" and what portion was caused by the filter, two identical runs were made except for the filter. The steady-state daughter concentration without filter was approximately 33% of the initial level while that for the run with filter was about 5%. Thus, steady-state daughter concentration with the filter was only one-sixth of the concentration without the filter. Since the ultimate reduction of the steady-state concentration was the object of the study, filter performance as reported includes "wall effect."

Tests were made of the performance of a metal viscous filter, a spun glass viscous furnace filter, a spun glass furnace filter coated with diatomite, a fiber glass insulation bat, and a high-efficiency pleated filter of CC-6 paper. Several runs were made on each filter type with the results combined to develop the curves of Fig. 5. The data for these curves represent essentially the same conditions of circulation (four minutes per air change) and have been adjusted to the same radon concentration. The results of the viscous filters were so nearly identical that only one curve is presented in Fig. 5. It is noted that the steady-state condition is reached more rapidly with the more efficient filters, but there is relatively little difference between the steady-state conditions for the CC-6, the fiber glass bat, and the diatomite-coated furnace filter. The improved performance of the furnace filter when coated with diatomite may be attributed to the static charge on the diatomite, the clogging effect of the coating, or a combination of the two. The specifications of the filters tested under the conditions represented in Fig. 5 are presented in Table I.

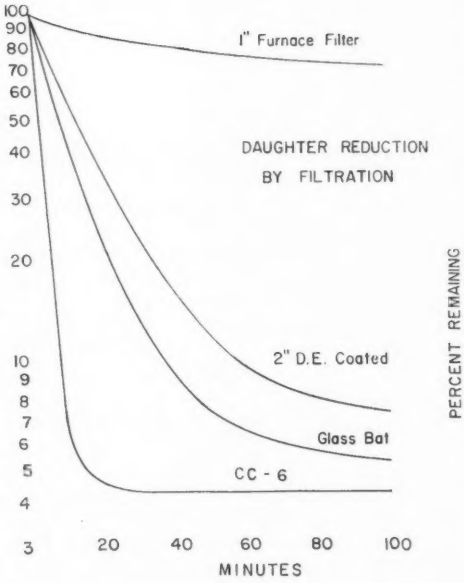


Fig. 5.

It is apparent from a comparison of the costs and results that the fiber glass insulation bat showed most promise, and subsequent investigations utilized this glass bat filter. The fiber glass insulation bat was used as purchased. The filter unit comprised a

TABLE I.
FILTER SPECIFICATIONS

Medium	Depth Inches	Area Sq. Ft.	Face Velocity for 4 Min./Air Change ft./min.	Static Drop Inches Water	Cost
CC-6	—	3.5	152	1.14	$44.00
Fiberglass bat	1"	3.5	152	1.4	0.35 (Plus 0.50 for frame)
DE coat	2"	2.2	242	1.24	1.90 (Plus small amount for diatomite)
Furnace	2"	2.2	242	0.11	1.90
Metal	2"	2.2	242	0.13	6.50

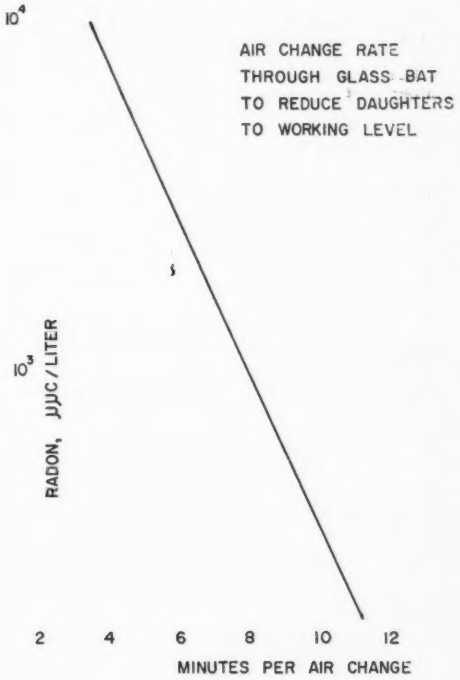


Fig. 6.

wooden frame covered with ¼-inch hardware cloth to which the fiber glass bat was cleated. The bat consisted of resin-bonded fibers having a median diameter of five microns with a standard geometric deviation of 1.5. The one-inch bat was packed to a density of approximately one-half pound per cubic foot.

In order to obtain reproducibility, radon was introduced into settled room air. The steady-state condition was determined for the room at four air change rates and at several specific radon concentrations. The steady-state daughter concentration in terms of the working level was plotted against radon concentration for each circulation condition. The curves for the various circulation rates were extrapolated to the ordinate through the working level value. The radon values at these intercepts were then plotted against the corresponding circulation rates and the curve of Fig. 6 was obtained. From this curve it is possible to determine the circulation rate through the fiber glass bat which would be required in the experimental chamber to maintain the daughters at the working level for various concentrations of radon.

It can be shown that the absolute efficiency of a filter evaluated in the closed chamber is equal to the daughter growth per unit volume within the time of one air change divided by the steady-state daughter concentration. If the time of daughter growth is determined from a circulation rate adjusted for short circuiting, the efficiency of the glass bat filter can be calculated to be about 65%. This is in agreement with measured efficiencies which ranged from 60% to 70%.

It is interesting to note that the penetration through the glass bat filter by radon daughters is 35% while this type filter is expected to have a penetration of less than 20% by count for the dust in room air.[13] Although the filtering velocities reported here are above the optimum for this type of filter, it appears more reasonable to explain the discrepancy by the fact that radon daughters are preferentially deposited on particles under 0.035 micron.[14] Verification of this explanation is found in the computed penetration of 15% for the CC-6 filter which when used under similar conditions is predicated to have a penetration of 0.013%.[15]

During the evaluation of filters, simultaneous samples taken at different sampling rates were observed to differ by wide margins. All comparisons made in this paper were made on the basis of samples taken at the same rate and therefore are not affected by the observed difference. Current activities include the investigation of the effect of sampling rate on sample concentrations. It is hoped that reliability of existing sampling methods for radon daughters can be established.

Field testing of a filtration unit under actual operating conditions has been initiated and preliminary results are promising. Future work will be devoted to further investigation of actual application of results obtained in this study.

Conclusions

THE WORK reported herein has shown that the control of radon daughters in mine atmospheres by adsorption of radon gas on media presently available is not practicable.

Successful reduction of radon daughter

concentration has been obtained by filtration through glass fiber filters. Methods of predicting necessary circulation rates for conditions encountered in the experimental chamber have been developed.

Acknowledgments

THE AUTHORS wish to express their gratitude to D. E. RUSHING, L. W. BREWER, and W. J. GARCIA of the chemistry section of the Occupational Health Field Station, Public Health Service, for their advice and help in making many of the analyses.

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Adsorption of Gases and Vapors

ON AEROSOL PARTICULATES

V. A. GORDIEYEFF, Chemical Warfare Laboratories
Directorate of Medical Research
Army Chemical Center, Maryland

THIS PAPER presents some results of a rather extensive study on the mechanism of interaction between vapors and airborne, sorbing particles.[1,2] The study has covered adsorption of vapors and gases by airborne solid particles and absorption by airborne droplets. This presentation will be limited to the discussion of the mechanism of adsorption by solid particles only. The limited time of presentation would not allow to discuss the process of absorption of vapors in liquid particles. This presentation will deal exclusively with the physical sorption of vapors, i.e. *volatile* substances only. No discussion will be given on the mechanism of sorption of *non-volatile* substances, impregnated on air dispersed particles. Irreversible sorption with a chemical reaction following adsorption of a vapor will be also omitted. This includes the sorptive processes resulting in a more or less irreversible hydration of the sorbing particles. The interest of this study has been centered around the airborne dust particles of the highest possible sorptive power, *i.e.*, porous materials. Littlle attention has been given to poorer sorbents, i.e. non-porous materials.

The process of adsorption has been extensively studied so far as the stationary sorbing beds are concerned. Practically no work has been done in studying the adsorption processes by airborne sorbent systems with the notable exception of adsorption by fine particles in atmospheres of saturated and supersaturated vapors in connection with the phenomenon of nucleation.[3,4]

It was found during an early stage of this study that the sorptive behavior of an airborne dust cloud could not always be estimated accurately on the basis of data obtained from studies of a stationary bed, made of the dust material. Thus, it was often necessary to study adsorption by the aerosols while they remained airborne. This resulted in a rather complicated apparatus and elaborate measuring methods. Their adequate description would take more time than it has been allowed for the entire

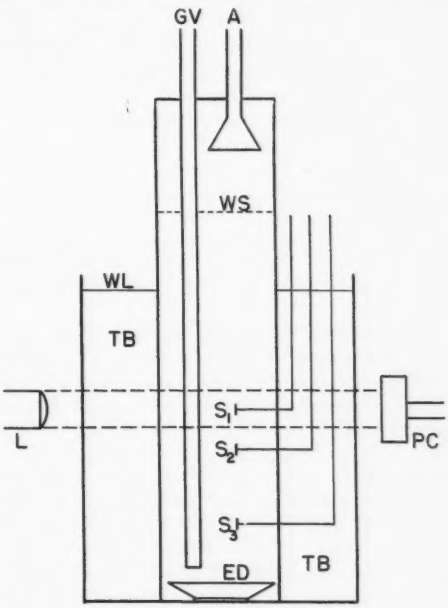

Fig. 1.
Aerosol Vapor Chamber
S_{1-3} — Samplers
ED — Evaporating Dish
L — Light Beam (Parallel)
PC — Photocell
A — Aerosol Inlet
GV — Diffusion Tube
WS — Wire Screen
TB — Thermostated Water Bath
WL — Water Level

presentation. The basic methods used in this study were based on: (a) the rate of vapor diffusion measured in the presence and absence of an aerosol (Fig. 1 shows a diagram of the diffusion chamber used in this study[5]); (b) sedimentation velocity of particles in atmospheres of sorbable vapors (this method was limited to relatively high vapor concentrations); (c) analytical determination of vapor distribution between the gas phase and the aerosol cloud; (d) radiotracer, and (e) light scattering techniques.

The mechanism of adsorption of vapors by porous dust particles is simple and does not differ, qualitatively at least, from that peculiar to the stationary beds made up of the same material (mother or bulk material). Years ago a theory was advanced[6] that airborne particles might be cushioned by thick, protective layers of the gas medium. Such layers were supposed to interfere with diffusion of sorbable vapors and to hinder adsorption of vapors. This study did not bring forth any definite evidence to support this theory. It seems that the observed differences in adsorption of vapors by mother dusts and their airborne fractions can be explained in terms of the diffusion mechanism according to the dynamic theory of adsorption.[7] These differences are rather *quantitative* than qualitative ones in nature.

The most important difference in the sorptive behavior between the mother dust and its airborne fraction goes back to the fact that the mass of the air suspended dust in any gas volume is severely limited by the aerodynamic conditions of the aerosol state. It is easy to imagine that one hundred grams of a sorbent may be placed in a container of one liter capacity, filled with a desired quantity of a sorbable vapor. But if we try to disperse the same sorbent in the same container, only a small fraction of the original 100 grams would become and even less stay airborne for any appreciable time. But the mass of the vapor may remain the same or may be even increased. Thus, the situation of the sorbing aerosol cloud is a peculiar one: in the process of adsorption of vapors from a gas in a stationary sorbing bed a large mass of adsorbent is in contact with a relatively low concentration of a sorbable vapor. But in the airborne form

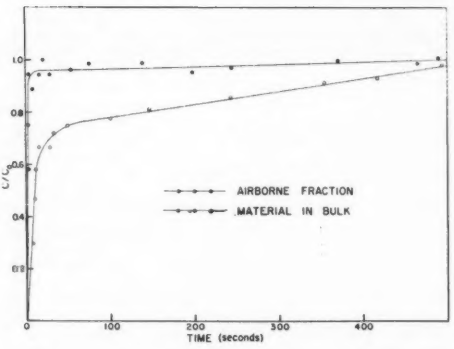

Fig. 2.
Adsorption rate of pyridine by activated charcoal dusts.

it is the adsorbent which is present in a low concentration: the mass of the sorbable vapor is, on the contrary, relatively large. This fact indicates that the amount of vapor which can be adsorbed on a sorbing aerosol would be a function not only of vapor concentration but of the aerosol content of the atmosphere as well.

Since an aerosol is a dynamic, continuously changing system the kinetics of the adsorptive process were of the primary concern to this study. Fig. 2 shows the rate of adsorption by a porous dust exposed to rather large concentration of a sorbable vapor. This figure indicates that the rate of adsorption by such a dust consists of two stages: the initial phase is that of an almost simultaneous adsorption, so fast that it could be measured in a few instances only and even then at low temperatures ($< 0°$ C). The second stage of the process is a much slower one and it usually extends *over the entire lifetime* of a dust cloud in the experimental chamber. In some instances this second stage of adsorption does not add significantly to the amount of vapor adsorbed during the first, rapid stage; but quite frequently it was impossible to equilibrate the sorbing dust cloud completely with the vapor since the lifetime of the cloud was not long enough to conclude the process.

Similarly, the reverse process of desorption occurs in two steps: the first step is that of a very rapid desorption where, in most instances, almost the entire vapor content of the cloud would be stripped completely off the particles within an im-

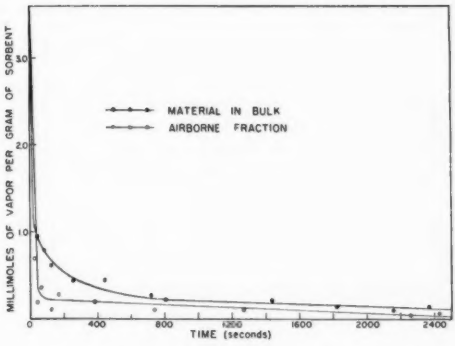

Fig. 3.
Desorption rate of iodine vapors sorbed on silica dusts (sil 54).

measurably short time. The trace amounts of vapor left on the grains would then either desorb very slowly or in some instances remain permanently fixed on the grains, forming most probably a semichemical bond. This residual amount which characterizes retentivity of the airborne adsorbent is invariably very small and seldom exceeds a fraction of 1% of the dust's own weight. Fig. 3 shows one of the few cases where the desorption rate could be determined with some accuracy.

Desorption from an aerosol cloud is especially fast and complete if an aerosol cloud passes close by to another sorbing system. Thus, if an aerosol previously exposed to a heavy concentration of sorbable vapors would be directed through a small bubbler filled with a good solvent for the adsorbed vapors, the aerosol stream may pass through it, although with some losses. But the particles escaping from the bubbler were found in all cases tested to be practically free of any but trace amounts of the previously carried vapors. If an efficient vapor scrubber was used the recovery of the vapors present in the scrubbed atmosphere, was practically the same whether a sorbing aerosol has been added or not.

The results of any study dealing with adsorption are best represented and understood in the form of the classical adsorption isotherms. Fig. 4 shows three isotherm curves. The top curve has been drawn for a porous material of excellent sorbing power (a microgel) exposed in its bulk form to a sorbable vapor; the second one represents

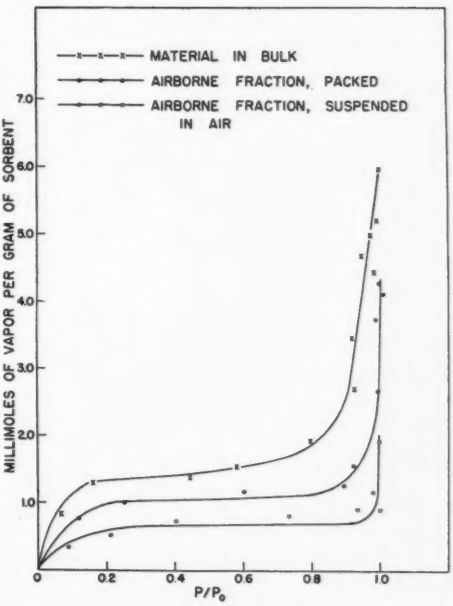

Fig. 4.
Adsorption of benzene vapors by activated alumina dusts (C 609) at 23.5° C.

the airborne fraction, after the dust has been dispersed in pure air, collected, packed into a tight little cartridge, and exposed in this form to the same sorbable vapor; the lowest curve shows adsorption of vapor by the airborne fraction as measured while it was airborne. The mechanism of sorption seems to be here essentially the same in all three cases since the shape of the isotherm curves is almost identical. The first curve indicates, however, that the bulk material has some components of higher sorptive capacity which are missing in the airborne fraction. It seems also that the sorptive power of a sorbing dust may be somewhat enhanced if it is tightly packed—probably due to formation of local higher pressure gradients and to the presence of intraparticulate spaces, as evidenced by the difference in the adsorptive capacities shown in the two lower curves of the graph.

Investigation of other similar porous dust —sorbable vapor systems revealed that in almost all cases the dust bulk had a somewhat higher adsorptive capacity than the airborne fraction. Fig. 5 shows that this

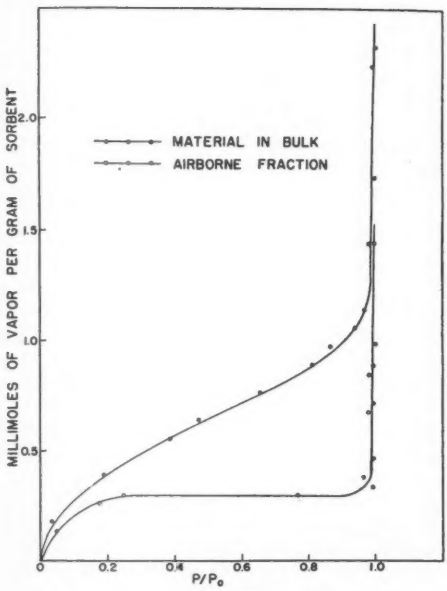

Fig. 5.
Adsorption isotherms of ammonia vapors by charcoal dusts at 17.8° C.

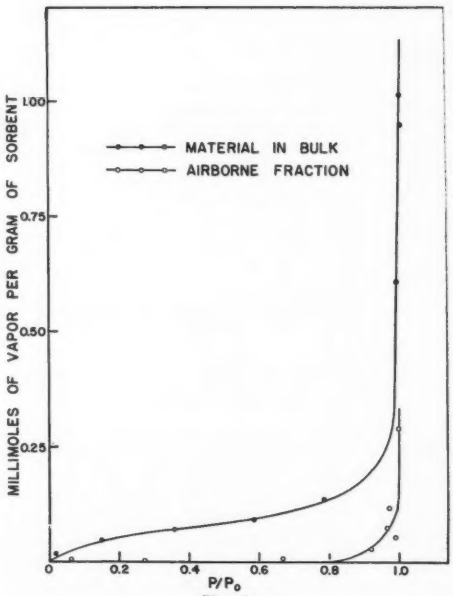

Fig. 6.
Adsorption isotherms of iodine vapors by silica dusts at 25.0° C.

difference in the adsorptive capacity is sometimes quite considerable and the isotherm curves for the bulk material and the airborne fractions may differ markedly. A very remarkable although not an infrequent case is shown in the isotherm curves of Fig. 6. The airborne fraction of the aerogel studied here shows hardly any detectable adsorption in the region of low and moderate relative vapor pressures. But it picks up a large amount of sorbate in the region close to the relative vapor saturation point. Here the adsorptive capacity does not differ very much from that of the mother material (represented by the upper curve). This is a very characteristic feature of adsorptive aerosols and may be also recognized in the previous graphs (Figs. 4 and 5). It is especially pronounced in the case of very fine aerosols like magnesium oxide or phosphorous oxide smokes. As the vapor content of the atmosphere increases and approaches the point of relative saturation a porous aerosol begins to adsorb heavily and the particles become coated with a thick deposit of the sorbate. Many porous grains acquire at this point a slurrylike appearance and finally form droplets of condensed liquid. Even relatively large particles (with diameters in excess of five micron) begin to act at this point as condensation nuclei and formation of a heavy secondary aerosol may be observed. At the same time, however, a heavy fall out sets in reducing the mass of the secondary aerosol.

It is a well known fact that the surface of a nonporous substance increases as the original volume is subdivided into smaller particulate units. It is an open question whether the adsorptively active surface increases at the same rate. In the case of a porous adsorptive substance the external surface is small as compared to the internal or pore surface. Most of the adsorbed vapor is present, anyhow, not in the form of surface adsorbed layers but as a condensed semi-liquid or true liquid, filling the adsorptive cells of the interior, *i.e.*, the tiny capillaries and cavities of the dust grains. It was found previously and confirmed during this study that grinding of a porous dust reduces its sorptive capacity although the external specific surface is increased in this process.[8,9] Obviously, many adsorptive cells

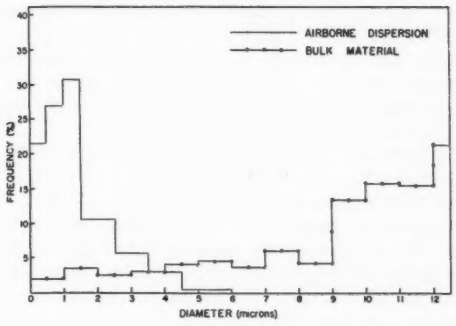

Fig. 7.
Particle size distribution in bulk material and airborne dispersion of an aerogel.

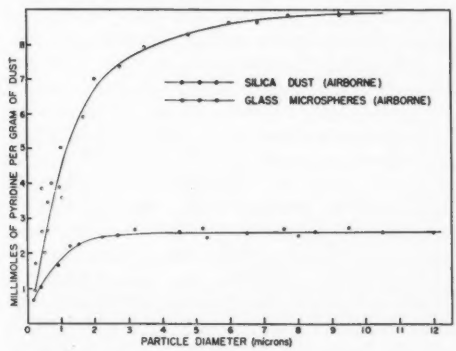

Fig. 8.
Adsorption of pyridine vapors by silica dusts and porous glass microspheres.

are destroyed in the course of such a treatment. The airborne fractions of porous dusts are usually produced by a more or less modified process of elutriation and consist mostly of fragments of the original more cellular dust grains and consequently exhibit a somewhat lower adsorption potential and capacity than the original material. Electronmicrophic examination of some grains in the studied dust dispersions seems to support these considerations.

There is no method available at the present time to disperse porous dusts in the form of monodispersed aerosols. The studied dust dispersion were necessarily polydispersed in their particle size distribution (Fig. 7 gives a typical particle size distribution pattern). If such a dust cloud was exposed to an atmosphere of sorbable vapors the larger cloud components represented—

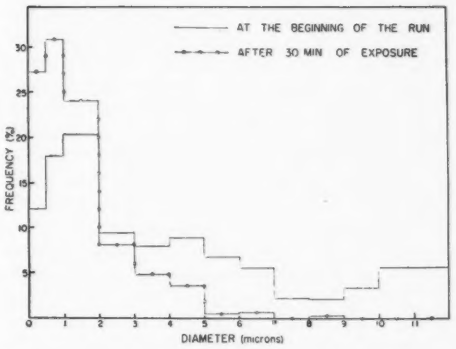

Fig. 9.
Adsorption of pyridine vapors on a silica gel dust (24 F). Effect of adsorption on particle size distribution of the airborne phase.

for reasons given above—areas of a higher adsorptive potential and vapor tended to leave the smaller members of the dispersion (*i.e.*, areas of a lower sorptive potential) to concentrate on the bigger particles. Since the adsorption and desorption rates are fast in an airborne cloud the distribution of sorbate may acquire soon a pattern similar to that shown in Fig. 8. The effect of the preferential or differential adsorption—as it may be conveniently called—is shown on two types of porous aerosols, one of a low porosity (glass particles) and another one of a very high porosity (silica aerogel). The differences in the region of smaller dimensions are here exaggerated (they may be actually smaller due to larger measurement errors in this size range) but the trend is clear. The preferential adsorption affects less aerosols in contact with vapor saturated or supersaturated atmospheres where the supply of sorbate is plentiful enough to satisfy all the vapor acceptors in the cloud. The effect decreases also if the size distribution of cloud particles approaches that of a homogeneous aerosol. A preferential sorption has a considerable influence upon the composition and airborne stability of a dust cloud since it tends to accelerate precipitation of the larger cloud components. Fig. 9 shows some effects of heavy preferential sorption upon particle size distribution in an adsorptive dust cloud.

In chamber work, the walls and other chamber surfaces become, after introduction of aerosol, coated with deposited aerosol ma-

terial. This material competes for the molecules of sorbate with the airborne material and since it consists usually of the larger grains than those still present in the airborne phase, it competes very successfully. This interfering effect of preferential adsorption is especially serious when working with small chambers and it is necessary either to compensate for it or use special techniques to reduce its magnitude.[10]

A cloud of a porous sorbing dust exhibits frequently some peculiarities which are difficult to explain. First of all, there is the so-called cloud effect. It occurs often when a dense dust cloud is exposed to a larger concentration of a sorbable vapor. It is characterized by a sudden turbulence followed by breaking up of the cloud with formation of secondary smoke puffs which usually settle down the chamber with a considerable velocity. At other times, heavier separate smoke puffs may form at the boundary between a dense cloud and the vapor carrying air. The appearance of such puffs is followed by their rapid precipitation out of the airborne phase.

The effect can be traced to a large heat of adsorption usually evolved at a fast rate when a dense adsorbent cloud would take up a large amount of an adsorbable vapor. Proper mixing techniques can minimize the effect although it was seldom possible to eliminate it completely when working with dense clouds and larger vapor concentrations: considerable losses of the airborne sorbing mass could be avoided rather as an exception than as a rule.

The density of the adsorbing clouds was found during this study to be an extremely important factor in the diffusion mechanism of vapors, and hence in the mechanism of their uptake by the adsorptive grains. It had an especially important and peculiar effect on the rate of adsorption: while it seemed to slow down the first fast stage of adsorption it accelerated the second, slow phase of adsorption. It seemed to have a less pronounced influence upon the rate of desorption.

The mode of uptake of the sorbate was found to have a significant effect on the specific sorptivity and retentivity of many dusts. Thus, dust materials exposed to a sorbable vapor under large pressures or impregnated with a volatile liquid substance, and then dispersed as clouds showed after equilibration a higher sorptive capacity. They also showed a significantly higher vapor retention after desorption than identical dust clouds exposed to vapors directly in the gas phase.

Although this study dealt primarily with the mechanism of adsorption of vapors by airborne porous particles on a broad physicochemical basis a lot of attention was paid to the problem of adsorption of various toxic vapors. It may be appropriate to close this paper by a brief discussion of this applied aspect of the investigation.

It has been claimed[11,12] that the inhalation toxicity of vapors may be affected by the presence of non-toxic aerosols. It has been claimed in particular that the *acute* toxicity of a vapor might be *increased* by the presence of an aerosol carrier. The explanation given for the effect was that it might be caused by adsorption of vapors on the aerosol particles. It was argued that such an adsorption would change the pattern of vapor penetration and retention causing more damage to the vital tissues of the respiratory system. Less attention was paid to another possibility that the presence of an inert aerosol may have some additive pharmacological action especially due to the presence of chemical impurities in the aerosol material or a direct or indirect physiological effect through changes induced in the pattern of respiration.

Reexamination of some of the claims to the aerosol effect in these and other laboratories, carried out simultaneously with this study[13] showed that a good deal of caution should be applied in evaluating these claims. But at the early stage of this investigation these claims were accepted rather uncritically and strong efforts have been made to correlate the toxic effects with adsorption of toxic vapors on aerosol particles.

These toxicological studies represent actually a separate extensive investigation and can not be fully described in this paper. It may be of some interest, however, to discuss very briefly the most important connections between these two studies. The physicochemical investigation has developed techniques and has supplied information about the mechanism of the sorptive process which were helpful in designing proper physiological and toxicological experiments to test the

effect of adsorption of toxic vapors by aerosols on the toxicity of the inhaled atmosphere. It was possible to select for any vapor, in the wide range of tested agents, the best possible air dispersable adsorbents, to determine their physical adsorptive characteristics and to predict within certain limits the adsorptive-desorptive patterns of various toxic vapor-adsorptive aerosol mixtures passing through the respiratory tract. Thus, it was estimated that unless the toxic atmosphere is practically saturated with the toxic vapors and the carrier aerosols are monodispersed and very fine, the amount of vapor adsorbed on the carrier particles would not significantly change the penetrating power of the vapor. This prediction was based on the estimated adsorptive capacity of aerosol particles able to penetrate and be retained in large numbers in the deeper parts of the lung, the vapor distribution between different classes of particles in a polydispersed cloud, on the concentration of the cloud which could be inhaled and retained without causing changes in the pattern of respiration, the extent of desorption and its rate during passage through the upper respiratory ways, and finally the scrubbing efficiency of the upper respiratory tract. It may be interesting to note that all the physiological and toxicological experiments, carried out so far, have confirmed (contrary to the previous claims) these predictions.

Thus, it seems probable that within the limitations of the scope of the study (only *acute* toxicities, for instance, were studied while no attention was paid to *chronic* toxicities) if any changes in *acute* toxicity of vapors should be observed, following addition of a dust cloud to the atmosphere, they should be rather ascribed to physiological, pharmacological, and perhaps other physical effects of the dust than to its *adsorptive* action. It was found, for instance that changes in the humidity of the inhaled atmosphere seemed to have a more profound effect on the toxic effects than the presence or absence of an adsorptive aerosol.

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Honorary Member

AT A MEETING of the Board of Directors of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION in Pittsburgh on November 14, CAREY P. MCCORD, M.D., was elected to Honorary Membership. The Board of Directors may elect as Honorary Members such persons as are particularly distinguished in the general field of industrial hygiene or in a closely related scientific field. The Association has extended this honor to only three other persons: DR. ALICE HAMILTON, DR. LUDWIG TELEKY and DR. ROYD R. SAYERS.

The Determination of Mercury in Air Samples and Biological Materials

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THE INCREASING use of highly toxic mercury compounds as commercial fungicides and insecticides stresses the need for a rapid and reliable method for measuring micro amounts of mercury in air and biological samples.

Existing methods for the determination of mercury in urine usually include long, tedious procedures involving ashing the sample with mixed acids, or boiling with oxidizing solutions of potassium permanganate or potassium chlorate. This paper describes a method for the cold digestion of urine with potassium permanganate and sulfuric acid, thus eliminating many hours of work.

The mercury is isolated by filtering the treated sample through a glass filter pad impregnated with cadmium sulfide. The pad, containing the mercury as the sulfide, is placed in a micro gas chamber connected to a G.E. Instantaneous Vapor Detector equipped with a recorder. The gas chamber is heated and compressed air passed through the system to carry the liberated vapor into the detector. The area under the curve traced by the recorder is proportional to the amount of mercury in the sample.

The method as outlined allows the determination of 0.1 to 10 ± 0.1 micrograms of mercury. Greater sensitivity may be achieved, however, this range was suitable for our purposes.

REAGENTS AND APPARATUS:

Distilled water used throughout
Concentrated sulfuric acid C.P.
Potassium permanganate—reagent grade
Reagent grade ammonia 28%
Hydroxylamine hydrochloride saturated aqueous solution
Universal pH indicator solution
Beckman G. pH meter
Cadmium acetate 10% aqueous solution
Sodium sulfide 10% aqueous solution
Glass filter pads—available from Mine Safety Appliance Company, Pittsburgh, in the form of sheets 8 inches by 10 inches.

STANDARD MERCURY SOLUTION: 1.354 g mercuric chloride is dissolved in water, and made up to 1 liter; 1 ml of this solution contains 1000 micrograms mercury (Hg). Smaller concentrations are obtained by diluting this stock solution, and should be prepared fresh about every two weeks as mercuric ions are adsorbed on glass from dilute solutions.

CADMIUM SULFIDE PADS: The glass filter pad is placed between two filter papers in a large Büchner funnel. The cadmium acetate and sodium sulfide solutions are alternately filtered through, beginning and ending with the cadmium, until the pad is a uniform brilliant orange. It is then washed several times with water, sucked dry, and placed in an oven at 100°C for one hour. Finally, it is heated in a muffle furnace at about 375°C for an hour, and stored in a dessicator until used. It is convenient to prepare pads about 15 cm in diameter, then cut these with a cork borer to the required size before use.

ABSORBING SOLUTION FOR AIR SAMPLES: Dissolve 20 g potassium permanganate in 800 ml of water, filter, add 100 ml of concentrated sulphuric acid and make up to one liter with water.

DETECTOR: A General Electric Instantaneous Vapor Detector connected downstream from the sample is used to detect the mercury vapor. Rather than plotting individual meter readings manually, a 2000 ohm, variable tap fixed resistor was incorporated in the detector in parallel with the meter. The

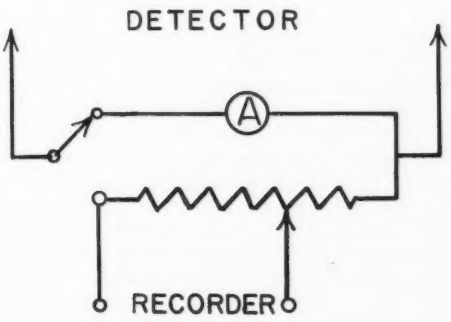

Fig. 1.

input terminals of a 0-50 millivolt recorder were connected across the resistor. By connecting the meter and resistor through a switch, it was possible to make readings using either the meter or the recorder. Power for the detector and recorder was supplied from a 115 volt constant voltage transformer to minimize possible interference from the line voltage fluctuations. (Wiring diagram Fig. 1)

Procedure

AIR SAMPLING: The air to be tested is drawn through two impingers in series, each containing 100 ml of absorbing solution. On completion of sampling, the solution is transferred to an erlenmeyer flask, and subsequently treated as a digested urine sample.

DIGESTION OF URINE: To 25 or 50 ml of urine in a 500 ml erlenmeyer flask, add 100 ml water, 2 g potassium permanganate, and swirl to dissolve, then add 10 ml concentrated sulphuric acid. Allow the solution to stand for about eight hours or overnight. If the permanganate color persists, continue with the analysis; if bleached, add an additional gram of potassium permanganate and allow to stand again.

Bleach the excess potassium permanganate with a few drops of the saturated hydroxylamine hydrochloride solution; add 10 ml 28% ammonia, four drops universal indicator, and adjust the pH to approximately six with dilute ammonia - dilute hydrochloric acid may be used if the end point is inadvertently passed. The pH of the first few samples should be checked with a pH meter until the correct color can be determined visually by the operator.

Heat the solution until it just begins to boil, then allow to cool; filter, using a water aspirator pump at the rate of about 50 ml per minute through a cadmium sulfide impregnated glass filter pad 20 to 30 mm in diameter set in a Gooch crucible. Rinse the pad with 100 ml water, 10 ml 50% methanol, and suck dry. Some urine samples contain a large amount of solid material; this should be removed by a preliminary filtration and discarded. To remove small particles, a filter disc of glass or paper may be placed over the cadmium sulfide pad.

The pad is now placed in the microgas chamber, around which copper gauze has been wrapped. This is heated gently with a bunsen burner, and compressed air is passed through the system to carry the liberated mercury vapor into the vapor detector. (See diagram Fig. 2.)

The area under the curve traced by the recorder is measured with a planimeter and

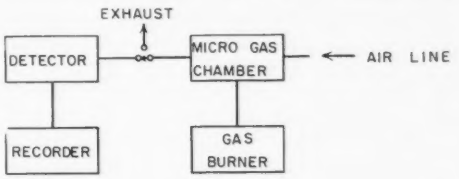

Fig. 2.

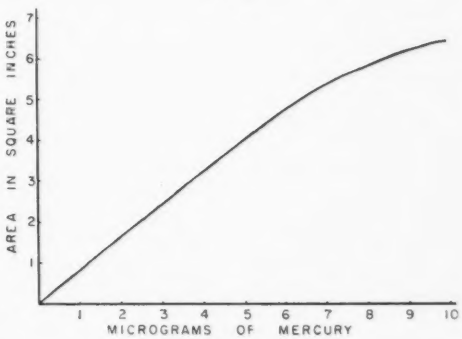

Fig. 3.

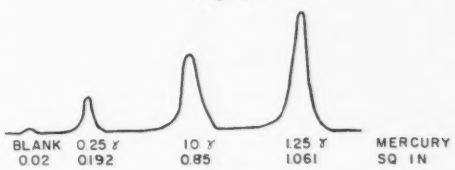

Fig. 4.

compared with areas obtained with standard amounts of mercury. The calibration curve obtained in this laboratory, plotting micrograms of mercury against area is shown in Fig. 3. Some characteristic curves are shown in Fig. 4.

A reagent blank should be run; if an appreciable area is obtained, the reagent contaminated with mercury is replaced; if the area is relatively small, the corresponding weight of mercury is subtracted from the samples.

Several normal urine samples should be tested; an average area corresponding to less than 0.1 microgram of mercury for a 50 ml sample was found in this laboratory. This value should be subtracted from the mercury found in contaminated samples.

Discussion

BALLARD AND THORNTON[1] used preignited asbestos fibres impregnated with cadmium sulfide to isolate mercury from organic solvent samples. The glass filter pad is somewhat easier to prepare; it is more convenient to handle a dry disc, and there is no possibility of thin spots in the filter through which the mercury could pass.

Isolation of mercury by electroplating on wire electrodes followed by distillation as described by Stock and Lux[2,3] requires a highly skilled operator, and proved to be less reliable than the conversion to mercuric sulfide. Separation of mercury by deposition on copper foil without external E.M.F. was either too slow[4] or too unreliable.[5]

The suggested rate of filtration of the mercury solution through the cadmuim sulfide pad in Ballard and Thorntons paper[1] was 4 ml per minute. No loss of mercury was found to occur when the rate was increased to 50 ml per minute.

Dithizone methods for mercury are not sufficiently sensitive and lack specificity. Copper, if present, must be removed. This method is specific for mercury; no other substance has the properties necessary to give a reading, *i.e.*, a sulfide more insoluble than cadmium sulfide and a low temperature of vaporization. Carbonaceous material will interfere, but should have been removed previously by filtration.

Solutions of organic mercury compounds such as phenylmercuric acetate and phenylmercuric chloride in dilute alcohol behave similarly to soluble inorganic mercury salts, *i.e.*, the mercury is removed quantitatively by filtering the solution through a cadmium sulfide pad. This is also true of the commercial fungicide Panogen (methyl-mercuric-dicyandiamide) manufactured by Panogen, Inc., Ringwood, Illinois.

Complete oxidation of biological samples is ensured by the presence of excess permanganate at the end of the eight hour digestion period. The danger of loss of mercury through volatilization is avoided by cold digestion.

In our experience with air samples, no measurable amount of mercury was ever detected in the absorbing solution of the second impinger, indicating that the samples were completely absorbed by the first solution.

An exhaust fan was attached to the air outlet on our vapor detector to prevent mercury contamination of the laboratory. This is advisable when a large number of samples are analyzed.

Following an overnight digestion an experienced operator is able to complete 20 to 25 samples in one day. The time required to prepare this number of samples for digestion is less than an hour.

The method provides for the determination of 0.1 to 10 $\pm$ .1 micrograms of mercury. More sensitivity could be achieved by increasing the speed of the recorder chart or by altering the range of the recorder from 50 millivolts to five millivolts or by a combination of both.

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The Management of Power Reactor Wastes

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ADEQUATE MANAGEMENT of the radioactive wastes from a nuclear power reactor industry has many aspects. The economic and public health aspects are immediately obvious. Somewhat less obvious are the relations between waste management and the reactor site location, transportation, the type of recovery process, agriculture, wildlife, liability insurance, mining, and sensitive manufacturing processes. A waste management procedure must be examined carefully from many points of view with the realization that errors will be difficult to correct; in fact, it may be almost impossible to recover the original condition once a serious error has occurred. The late Dr. Cipriani put this clearly when he said: "The insidious spread of radioactive contamination is such that original backgrounds are never restored even after prompt and thorough decontamination efforts."[2]

In the current wave of enthusiasm for nuclear power, the management of wastes has the position of a stepchild. One risks being branded a Cassandra if he points out, as I am doing, that waste problems may make or break the nuclear power business. A lawyer active in the atomic power field has pointed out that improper disposal of reactor wastes may involve as large a sum for public liability as one of the reactor accidents now receiving so much attention.[13] It may not be fashionable to ponder these problems, but it is nonetheless important to do so while there is still time to avoid serious mistakes.

The usual term for this subject is "waste disposal." The word "disposal" connotes a finality not easily achieved in this connection. As the title of this paper indicates, I prefer the words "waste management" with their implication of a continuing effort.

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In the final analysis there are three methods for managing radioactive wastes from a reactor plant: (1) Release to the environment, in general after a storage period to allow some decay, and always under conditions of adequate dilution and dispersal. (2)

A power reactor industry presents some unusual problems in waste disposal. Reactor wastes have several unique properties: (a) enormous amounts of radioactivity, (b) extreme and long-lived toxicity which cannot be rendered benign by treatment, and (c) consequent difficulty of recovering from errors and accidents. These properties, and the ability of some living organisms to concentrate materials from their environment, preclude the release of significant quantities of the wastes. A possible exception is 9.4 - year krypton-85, which cannot be concentrated biologically.

Most reactor wastes are now stored in underground tanks; this is not a permanent solution. Fixation in concrete, clay and glass is under study; the rates of release must be very slow. Utilization of the wastes as sources of radiation, heat and rare elements affects the problem only insofar as it helps pay the disposal costs.

Reactor waste management will probably take the following form: (a) separation and storage of the inert gases until controlled release to the atmosphere is possible, (b) concentration of the other wastes in solid or liquid form and storage for 10-20 years, (c) separation and storage of the strontium and cesium, and (d) fixation of the remainder and burial in the ocean or in dry ground.

Permanent storage on the plant site under conditions of adequate shielding and perpetual care. (3) Shipment off site for "ultimate" disposal after concentrating and packaging the material in a manner suitable for shipment.

Magnitude of the Problem

A NUMBER of authors have estimated future power requirements and the part nuclear power will play in meeting these requirements.[4,9] The following discussion is based on the figure 750,000 megawatts of installed nuclear heat power by the year 2000 in the United States, and 2,500,000 megawatts in the entire world.

A 750,000 MW nuclear power industry will consume fissionable material at the rate of some 300 tons per year, and will produce fission products at the same rate—300 tons per year. The corresponding figure for the world-wide industry is 1,000 tons. These are remarkably small bulks, both of fuel and of wastes, but there is more to the story.

The fission products from a typical power reactor (300 MW) operated for a year will contain the order of one million curies of radioactivity, one year after they have been removed from the reactor. These year-old ashes will produce heat at the rate of one thousand BTU's per second. Both the radioactivity and the heat output will decline with time, but meanwhile the reactor continues to produce fission products.

Suppose all the fission product wastes from a single 300 MW reactor are dumped into a vat. New activity is added, while the natural decay proceeds. In some 50 years an approximate equilibrium will be reached at a level of the order of 100 million curies.

In addition to the fission products, anything which has been in the reactor will be radioactive. Neutron capture induces radioactivity in the coolant, in materials and equipment, and in the reactor shield. Usually the total amount of induced activity will be very small compared to the activity of the fission products, but in the case of a sodium-cooled reactor, the activity induced in the sodium by neutron capture may amount to as much as 1% of the fission product activity. Fortunately sodium-24 decays quite rapidly (about a factor 10 every 48 hours), so time is a convenient solution to this problem.

Materials and equipment subjected to the neutron field of the reactor will contain induced radioactivity characteristic of the chemical elements which compose them. This activity will exist throughout the material and the only way to cope with it is to store the objects in a suitably shielded pit until the radioactivity has decayed to innocuous levels. The cobalt present in stainless steels extends the decay period to many years. Examples of materials and equipment subjected to neutron fields are control rods, structural members, instrument sensing elements, coolant, plumbing, reactor components and fuel element hardware.

Materials and equipment in contact with substances which have passed through the reactor will be contaminated with induced activities and fission products which have escaped from the fuel elements. This activity will exist only on the surface and can be removed, in principle at least, by decontamination methods. Decontamination is not a waste disposal method; it is simply a means for transferring radioactivity from a place where it is not wanted to wash solutions, dust bags, filters, traps, swabs, etc.

The total induced activity and contamination will be a very small fraction (probably far less than 0.01%) of the total fission product activity. However, the control and disposal of this activity will demand a comparable degree of skill and effort because of the diversity of forms and concentrations in which it will appear.

The Nature of the Wastes

THE PRIMARY fission products consist of many isotopes of many elements, but only a few of these are important in long-

TABLE I.
FISSION PRODUCTS OF PRINCIPAL INTEREST IN WASTE MANAGEMENTS

Isotope	Half-life	MPC in Air (7) (curies per cc)	MPC in Water (7) (curies per cc)	Activity at Equilibrium—2,500,000 MW World Industry (4,9) (curies)
Sr-90	25 yr.	2×10^{-10}	8×10^{-12}	1.2×10^{11}
Cs-137	33 yr.	2×10^{-12}	1.5×10^{-9}	1.4
Ce-144	280 da	7×10^{-13}	4×10^{-8}	1.2
Ru-106	1.0 yr.	3×10^{-14}	1×10^{-7}	0.11
Zr-95	65 da	4×10^{-12}	4×10^{-9}	1.4
Pm-147	2.6 yr.	2×10^{-12}	1×10^{-6}	0.58
Kr-85	9.4 yr.	3×10^{-12}	——	0.06

range considerations. Those of principal interest are given in Table I. With the exception of krypton-85, they will occur as solids or liquids, depending on the fuel processing and waste treatment methods. The greater part of the fuel waste will be composed of process chemicals.

Among the fission products are some of the most toxic materials known. There is nothing that can be done to detoxify them except to wait for radioactive decay, and decay is a slow process for some. Strontium-90, the single most troublesome isotope, decays with a half-life of 25 years.

Any considerations of waste management must be based in one way or another on the accepted values for the maximum permissible concentrations (MPC) for the constituents of the waste. Certain precautions are necessary in applying the available MPC figures[7] for this purpose, and it is well to understand these at the start.

First, it is important to realize that the total hazard in an environment is the sum of the hazard of each radioactive constituent of the environment. For example, an atmosphere containing both the MPC of a strontium-90 aerosol and the MPC of krypton-85 is at twice the acceptable breathing concentration. The situation is similar to a joint checking account used by several people, none of whom pays any attention to the withdrawals made by the others. Radioactivity in air, in water and in food, as well as radiation exposure, both occupational and medical, are all believed to draw on the same account.

The second precaution which must be observed in using MPC's is that they are intended as maxima, in a sense crudely analogous to the yield point of steel. Just as it is not good engineering practice to design a bridge so that every member is loaded to the point of failure, it is not good health physics practice to design a waste disposal system so that areas in the public domain are at the MPC for radioactive material.

The third precaution in using MPC's concerns mixing and dilution. There are several obvious mechanical limitations to ideal mixing, and there is also at least one rather subtle limitation. Some biological organisms have a remarkable ability to extract certain elements from their surroundings. Concentrations as great as a hundred thousand times that of the environment have been observed in some cases. This retrograde dilution has brought the suggestion that at least one MPC value (phosphorus-32) be substantially reduced.[12]

Even if one chooses to ignore these limitations, he finds that the oceans of the world are scarcely large enough to receive all the wastes from a 2.5 million MW nuclear power industry.[9] It is obvious that these wastes cannot be turned loose in the world.

The design of a waste disposal system requires that criteria for maximum safe concentrations in the public domain be established. In view of our limited knowledge of the biological effects of radiations and radioactive materials, and in view of the irreversible nature of waste release, it is clear that very conservative criteria must be used.

Release to the Environment

RADIOACTIVE wastes can be diluted and dispersed into the environment, following the methods and procedures used for many industrial wastes: (1) release into streams, rivers, lakes and oceans, (2) release into the atmosphere, and (3) release into the ground. We shall consider each of these methods briefly to gain some idea of their potentialities for handling the wastes from a power reactor industry.

Release into water: The British have carried out some investigations with a pipeline running two miles out into the Irish Sea. They conclude that the maximum safe rate of disposal is of the order of 100,000 curies per year.[3] A figure of between 10 and 100 curies per year is probably more nearly typical for inland plants.

Release into the atmosphere: A 300-foot stack can safely dispose of perhaps 10 curies per year of fission product activity in the form of gases and small particulates (less than 1 micron). If the effluent is only an inert gas, such as krypton-85, perhaps as much as 10,000 curies per year can be released.

Release into the ground: Open pits, cribs, dry wells, deep wells, abandoned salt mines and oil wells have been used or suggested as means for waste disposal.[1,6,10] Figures of the order of 10,000 curies are given for some of these, but the great variation of local geological conditions makes any gen-

eralization futile. The exhaustive geological and hydrological studies necessary to select a location and a method suitable for ground disposal,[11] the great uncertainties about subterranean water flow, the continued expense of monitoring and logging, and the difficulty or impossibility of correcting errors all contribute to make ground disposal unattractive for general use.

In a few special locations it may be possible to release significant quantities of fission wastes into the ground or the sea. It may also be possible to release the 6,000 curies of krypton-85 (0.13 cu. ft. at NTP) produced each year by a 300 MW reactor to the atmosphere. It is clear, however, that release to the environment cannot be used to dispose of the bulk of reactor wastes. In fact, at most plants, release to the environment will be no more than adequate for the inevitable and irreducible leaks through filters and traps and the low-level liquid and combustible wastes from laboratories and decontamination operations.

Concentration and Confinement

SINCE it is apparent that dilution and dispersal will solve few of the reactor waste problems, we turn to concentration and confinement methods. The usual concentration methods, evaporation, combustion, ion exchange, electrodeposition, etc., are applicable to these waste materials. The heat and radiations given off by fission products introduce some complications, but none of the difficulties appear to be insurmountable. Confinement of the wastes is another matter.

At present, almost all high-level wastes are stored in underground tanks. This is not regarded as a permanent solution to the problem. The tanks are expensive to install (the order of one cent per curie[10,14]); they require constant surveillance, and they are subject to leaks, earthquakes and other accidents.

Appreciable quantities of intermediate- and low-level wastes are encased or incorporated in concrete, sometimes poured into steel drums, and either stored on dry land, or dumped far out at sea. Transportation costs are large, and it does not seem likely that this method can meet the requirements of a nuclear power industry.

The search for permanent containment methods goes on actively, but the criterion of permanence is very stringent in this field. The activity of the fission products produced in one year by a 300 MW reactor amounts to some 6,000 curies 100 years later, and 500 curies after 1,000 years. Glueckauf[4] has pointed out that if the strontium and cesium are removed, the activity remaining in the wastes decays much more rapidly, reaching one-thousandth of the one-year activity in less than 10 years. The degree of permanence for wastes freed of strontium and cesium need be far less than for the unseparated waste.

Among the methods being investigated for permanent confinement are fired clays and glasses,[5] concrete and steel. Heat, radiation damage, solubilities, and the action of weather, time and tide combine to make the specifications for an acceptable method truly exquisite.

An important feature of permanent confinement is the choice of the final resting place for the packaged waste. There have been numerous suggestions: burial in dry ground, stagnant ocean deeps, sea canyons in the continental shelf, deep sea muds, perma-frost areas near the arctic circle, ice caps, caves, and, of course, rockets to the moon. Amid this wealth of suggestion, two things stand out. The first is that oceanographers strongly favor land disposal, while geologists show a decided preference for ocean burial. The other outstanding feature is the important part that transportation plays in all the disposal methods. Transportation of such materials is possible, even on the scale envisioned here, but it is certainly the stuff of which galloping nightmares are made.

Utilization of the Wastes

THE POSSIBLE utilization of fission products for processing, sterilization, radiography, heat, etc. is receiving considerable attention. It is sometimes implied that utilization will solve the disposal problem. It is true that such uses will provide storage for a time, but when the material has decayed to a level where it is no longer useful, say 3 to 5 half-lives, disposal once more becomes a problem. Widespread use of such material brings with it the increased probability of accidental release. The only contribution that utilization of fission product wastes

will make to their ultimate disposal is some financial assistance in defraying the cost of final treatment.

Summary

IN THE LIGHT of present knowledge, reactor waste management appears likely to take the following form: separation and storage of the inert fission gases until controlled release to the atmosphere is possible; concentration of the other wastes in solid or liquid form, and storage under carefully controlled conditions for 10 to 20 years; separation and permanent storage of the strontium and cesium; fixation and packaging of the remainder and burial in dry ground or in the ocean. Subsequent development, either technical or biological, may modify this profoundly.

There are three types of problems in the management of wastes from a power reactor industry: public health problems, economic problems and technological problems.

Consideration of the public health problems must be in terms of centuries and must take account of our meager understanding of long-term biological effects in general, and of genetic effects in particular. Such considerations must be made with the realization that release of radioactive wastes is an irreversible process. Extreme conservatism will be the guiding principle in attacking public health problems.

The economic problems concern the costs of disposal methods, including the requisite monitoring and control, and also the insurance and other costs associated with transportation and accidents. If there is to be a major nuclear power industry, the waste management costs must be a small fraction of the total power cost. Current estimates[4,9,10] are that this will actually be the case, but cost estimates at the present stage of development have about the same degree of reliability as the MPC figures.

The technological problems are those of providing methods which meet the boundary conditions imposed by public health requirements on the one hand, and economic requirements on the other. Among these problems are heat, radiation damage, solubility and transportation. A method meeting all the requirements has not as yet been demonstrated.

In conclusion, it should be emphasized again that the management of radioactive wastes is of critical importance to a power reactor industry, but even more, it is of world-wide significance and demands careful planning by national and international health authorities.

Decisions regarding standards and methods will have to be made in the near future. If the standards are to be both reasonable and safe, thoughtful consideration must be given to the available information and efforts to extend our knowledge in this field must be increased.

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A Low Dose Range, Chemical, Radiation Detector for Personnel Monitoring

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THE EVER-INCREASING application of atomic energy to the needs of industry, education, research, and government has increased the problems of the health physicist. One of the duties of the radiation expert is minimizing radiation exposure to man. One of the most important methods of reducing this danger has been the development of suitable radiation detection instruments for personnel monitoring, area monitoring, and general survey.

To record the extent of external radiation, most personnel monitoring systems utilize the two following indications: (a) blackening of photographic film and (b) the discharge of a condenser meter. The condenser meters are read daily, and the film badge is processed weekly. However, film badges are developed every time a condenser meter indicates that high radiation exposure may have occurred.

In many instances, personnel, such as secretarial employees, will never be exposed to any radiation except background radiation and the weekly processing of their film badges is costly and unnecessary.

A thermo-stable chemical detector capable of measuring doses lower than 1 r would have innumerable applications. This paper deals with the properties and production of such a low range radiation detector.

Preparation and Evaluation

REAGENT grade tetrachloroethylene is fractionated in a high efficiency still to a constant refractive index. The distillate is collected into a thoroughly cleansed pyrex container and overlayered with a thiourea, acidimetric dye-water solution. The container is then shaken repeatedly to remove the water-soluble acids that may have been produced by autocatalytic decomposition during the fractionation process. The distilled tetrachloroethylene is then stabilized with alcohol and thiourea.

Tetrachloroethylene responds to X- and gamma radiation, producing stable, water-soluble acids. If a dosimeter is given a known dose of radiation, the radiation-generated acids can be extracted with an acidimetric dye and back-titrated with 10^{-3} normal sodium hydroxide to its original pH. A calibration value for the number of micromilli-equivalents of acid per roentgen can then be obtained. Evaluation of unknown dose exposures is accomplished by titrating the exposed dosimeter and determining the number of milli-equivalents of acid generated by the unknown dose. If the number of micromilli-equivalents of acid per roentgen, obtained when calibrating the system, is divided into the number of micromilli-equivalents of acid generated by the unknown dose, the result is the unknown dose in roentgens. Titration techniques afford accuracy to $\pm$ 10%. Spectrophotometric analysis yields an accuracy of $\pm$ 3%. Simple visual color comparison of the overlayering acidimetric dye in various stages of its color transition affords accuracies of $\pm$ 20%.

A dosimeter, flame-sealed in a Neutraglass ampoule, with a hydrocarbon-to-dye ratio of approximately 6/1, will complete a color change from red to amber when exposed to 3 r. There is no decrease in radiation sensitivity during the shelf life of this dosimeter, which is approximately four months.

An undesirable property of this dosi-

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TABLE I.

EFFECTS OF VARYING THE EFFECTIVE ENERGY OF X- AND GAMMA RADIATION ON ACID FORMATION FROM THE ALCOHOL-THIOUREA STABILIZED TETRACHLOROETHYLENE DYE-WATER SYSTEM

Radiation sources	Radiation yield (in Meq acid x 10^{-6}/ml/r at different mean effective energies)
*40 KV effective** (260 KVP x-ray unit operated at 100 KVP, 18 Ma, 0.25 mm. Cu, 1.0 mm. Al filtration)	4.5**
*65 KV effective** (260 KVP x-ray unit operated at 150 KVP, 18 Ma, 0.25 mm. Cu, 1.0 mm. Al filtration)	4.0**
*190 KV effective** (260 KVP x-ray unit operated at 250 KVP, 18 Ma, with 0.25 mm. Cu, 1.0 mm. Al, 0.5 mm. Pb filtration)	3.0**
*1,200 KV effective** (Co^{60})	0.5**

*Radiation rates varied from 1 r/min to 10 r/min.

**Each value represents a mean obtained by titrating 20 samples; titration was done with 10^{-3} N NaOH.

TABLE II.

EFFECTS OF VARYING THE DOSE RATE OF X- AND GAMMA RADIATION ON ACID FORMATION FROM THE ALCOHOL-THIOUREA STABILIZED TETRACHLOROETHYLENE DYE-WATER SYSTEM

Radiation rates*	Radiation yield (in Meq acid x 10^{-6}/ml/r at different mean effective energies)
10 mr hr 83 mc Co^{60}	0.50**
1 r hr 100 mc Co^{60}	0.50**
4 r hr 100 mc Co^{60}	0.50**
10 r min (5 curie Co^{60})	0.50**
100 r min (5 curie Co^{60})	0.30**

*Total dose delivered was 10 r regardless of rate.

**Each value represents the average obtained by titrating 15 samples; titration was done with 10^{-3} N NaOH.

meter system is its pronounced light sensitivity. This can be controlled, however, by the use of proper transparent ultraviolet absorbing shields.

Radiation Characteristics

ENERGY DEPENDENCE: The energy dependence of the tetrachloroethylene-dye-water dosimeter somewhat parallels the energy dependence of bare film. The peak response, as measured by acid production, is directly related to photoelectric absorption. Energy dependence decreases as Compton scattering begins to predominate, and the systems become energy independent above 0.6 mev. Energy independence to 80 KV can be achieved by shielding the systems with 0.5 mm of lead. (See Table I.)

DOSE RATE DEPENDENCE: Alcohol-thiourea stabilized, tetrachloroethylene dosimeters are rate independent from 10 mr/hr to 10 r/min. Dose rate studies in this laboratory have been varied from 10 mr/hr to 100 r/min. (See Table II.)

TEMPERATURE DEPENDENCE DURING IRRADIATION: The tetrachloroethylene dosimeter system is temperature independent (± 5%) during irradiation, through a temperature range of 15°C to 35°C. (See Table III.)

DOSE ACID LINEARITY: The tetrachloroethylene dosimeter system shows a linear relationship between radiation dosage and the total acids liberated by the halogenated hydrocarbon as long as the dose rate is not varied. Linearity of acid production exists to doses greater than 10,000 r (See Table IV.)

RELATIONSHIP BETWEEN COLOR CHANGE (pH) AND DOSAGE: The acidimetric dye used in the tetrachloroethylene-dye-system has two peak absorption bands, 630 mμ and 450 mμ. As the pH of the dye is reduced from 6.3 to 5.2 (red to yellow) the percentage

TABLE III.

EFFECT OF VARYING TEMPERATURE DURING IRRADIATION ON THE ACID PRODUCTION FROM THE ALCOHOL-THIOUREA STABILIZED TETRACHLOROETHYLENE DYE-WATER SYSTEM

Temperature conditions*	Radiation yield (in Meq acid x 10^{-6}/ml/r when irradiated after stabilizing at different temperatures)
15.0°C	0.50**
20.0°C	0.50**
30.0°C	0.50**
40.0°C	0.55**

*Dosimeters exposed after four hours equilibration in a constant temperature water bath.

**Each value represents a mean of 15 titrations; titration was accomplished with 10^{-3} N NaOH. Total dose was 10 r at the rate of 10 r/min.

NOTE: All samples were flame-sealed in 8 mm Neutraglassiliconed ampoules.

TABLE IV.

LINEARITY OF ACID PRODUCTION: THE EFFECT OF VARYING THE TOTAL DOSE (ALCOHOL-THIOUREA STABILIZED TETRACHLOROETHYLENE SYSTEM

Total dose*	(Radiation yield in Meq x 10^{-6}/ml/r)
10 r	0.50**
100 r	0.50**
1,000 r	0.50**
5,000 r	0.50**
10,000 r	0.50**

*Dose rate = 10 r/min, Co^{60}.

**Each value represents a mean of 15 titrations; titration was accomplished with 10^{-3} N NaOH.

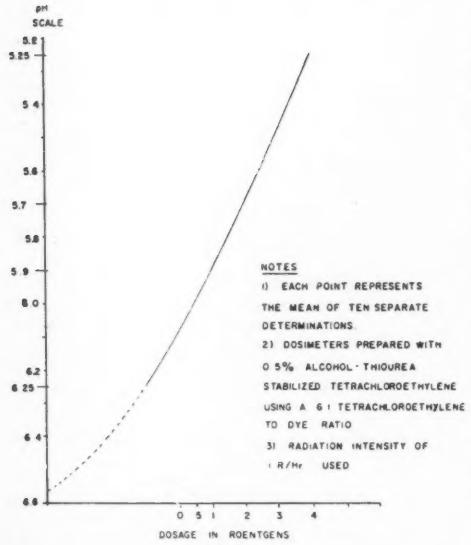

Fig. 1.
Relation between pH of chlorphenol red and dosage of Co^{60} gamma radiation.

transmission at each band in the spectrophotometer changes inversely; however, the ratio of the two readings is related to pH, provided that the dye concentration, tube size, light source, and glass thickness are held constant. (See Fig. 1.)

Discussion

ALTHOUGH film has several disadvantages, its desirability as a monitoring device should be recognized, with particular reference to its low cost and the permanence of the record it provides. The tetrachloroethylene-water-dye system should not be considered a competitor of film. Its most obvious application is that of a companion radiation detector.

If this dosimeter is not shielded with 0.5 mm of lead, it is to be considered only a detector, because of the spurious readings that can arise from its inherent spectral dependence. This characteristic of spectral dependence is an advantageous one, however, for it yields an increased acid production per roentgen absorbed, thus accelerating the color change of the overlaying dye. This color change can be brought to the attention of the health physicist and the employee's film badge processed. If the detector has changed color because of low energy radiation, this will be identified by the film badge and a more precise reading obtained for the employee's record. Further, if we assume the quarterly tolerance to be 3.9 r, then the detector is reliable for the visual evaluation of doses less than 1 r regardless of energy.

The frequency of film badge processing must be dictated by specific policy. However, quarterly film badge processing is made possible by the use of the detector system.

Conclusions

THE PROPERTIES of a low range chemical dosimeter have been presented. This device can be used as a direct reading dosimeter for measuring exposure to radiation dose from 500 mr to 3 r with an accuracy of $\pm$ 20%. A concept of quarterly film badge processing is made possible as long as the dosimeter is properly shielded for light sensitivity.

Acknowledgments

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Anatomical Charts

THE INDUSTRIAL Nurses' Section of the Illinois State Nurses' Association has sponsored the preparation of a series of anatomical charts in simplified form. Sixteen charts in two colors on 8½" x 11" sheets make up the series. The charts are available at $2.50 per set from Illinois State Nurses' Association, 6 N. Michigan Ave., Chicago 2.

THE ANALYSIS OF AIR FOR

Halogenated Hydrocarbon Contaminants

BY MEANS OF ABSORPTION ON SILICA GEL

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SEVERAL general methods have been used for the determination of halogenated hydrocarbons in air namely, direct combustion,[9] absorption in a liquid,[5,7,10,11,13] adsorption on silica gel[4] with subsequent alcoholic extraction,[2,6,8,12] and absorption on specially prepared activated charcoal followed by combustion of the charcoal and contaminant.[3] The direct combustion method is simple, rapid and accurate, but cannot be used in areas where the possibility of an explosive atmosphere exists or where no electricity is available. On the other hand, absorption in a liquid and adsorption on silica gel with alcoholic extraction are both techniques that allow sampling under most conditions but which require time-consuming and cumbersome analytical techniques after samples have been obtained. Adsorption on charcoal is efficient but this technique does not allow reuse of the adsorbant. Both the direct combustion and the liquid adsorption methods make necessary a quantitative transfer of liquid in the field, a procedure which has obvious disadvantages.

By combining the silica gel adsorption technique with the direct combustion technique a method has been devised which offers the advantages of both and circumvents the disadvantages of each. This method consists essentially of using silica gel for sampling and combustion for analysis. An air sample is taken on silica gel using an explosion-proof pump in an area where an explosion hazard exists or a spark proof hand pump as the source of suction where electricity is not available. The contaminant adsorbed on the gel is desorbed at a later time by heating the gel in an air stream and decomposed by passing that air stream through a combustion furnace to yield halogen and halogen acid which are absorbed in a solution and determined by suitable analytical procedure. In the field the only transfer is that of silica gel from an adsorbing vessel to a sample bottle, and the necessary quantitative transfer of solutions is left for the laboratory. This technique has been used at the Biochemical Research Department of The Dow Chemical Company for the past 10 years with nearly unqualified success. Halogenated hydrocarbons with boiling points ranging from -28 to 190°C have been determined with this method.

Although the combination of silica gel for sampling and combustion for analysis has been proved only for halogenated hydrocarbons, there seems to be no reason why it should not be successful with other classes of compounds. The two criteria which must be met are that quantitative adsorption on silica gel must be assured and that identification of the material after combustion must be unambiguous.

Description of the Technique

AIR SAMPLING: A list of materials and equipment which have been found to be satisfactory for sampling air for halogenated hydrocarbons using silica gel is presented in Table I. This list is not exclusive as no attempt has been made to examine all materials and equipment which might prove successful in this application.

A carrying case for the items listed on Table I has been found to be convenient. This case, along with the sampling equipment is shown in Fig. 1. A suction pump and a means of determining the volume of air passed through the adsorber is neces-

TABLE I.
MATERIALS AND EQUIPMENT FOR AIR SAMPLING WITH SILICA GEL

1. Silica gel. About 35 g is required for each sample. Suitable gel may be purchased from The Davison Chemical Corp., Baltimore 3, Maryland, as "Part No. 05-08-05-215, mesh 6-16, type 3."
2. Sample Bottles. Any 2 oz sample bottles with either ground glass stoppers or screw tops are satisfactory.
3. Adsorbing vessel. A satisfactory adsorber is diagramed on Fig. 2. The sintered glass support may be obtained from Ace Glass, Inc., Vineland, New Jersey, as "fiber glass filter tube, porosity B" in either 3 or 4 cm diameter.
4. Funnel. A glass funnel with a minimum stem diameter of 9-10 mm is helpful in transferring gel from the adsorber to the sample bottle.

sary. An electric pump kit which includes a rotameter is convenient and is also shown in Fig. 1; however, any type of pump is satisfactory so long as the air flow rate is steady. The length of time of sampling and the air flow rate used will depend primarily upon the concentration of contaminant in the air, the sensitivity of the analytical method, and the operation being evaluated. For very high vapor concentrations a flow rate of a few hundred milliliters per minute is adequate. For low vapor concentrations or short sampling times a flow rate of three liters per minute will usually be satisfactory, but should not be exceeded except on the basis of experimental verification of adsorption at the higher rate. Samples so taken can usually be held at least a week prior to desorption and analysis without loss of the contaminant on the gel.

AERATION AND COMBUSTION: A list of materials and equipment necessary for satisfactory performance in the aeration and combustion step is presented on Table II. The absorber listed is constructed in the same manner as the adsorber used for air sampling and, indeed, may be the identical vessel. This type of absorber has been found to be ideal for both applications, but other types might well be as successful. In addition to the equipment specified on Table II, a suction pump is necessary to draw air through the aeration and combustion train. Flow rate of this air is important and therefore, a rotameter in the line is recommended. Some arrangement is also necessary to protect the pump from water. A cold trap and tube of a desiccant such as calcium chloride, magnesium sulfate, or silica gel can be used for this purpose.

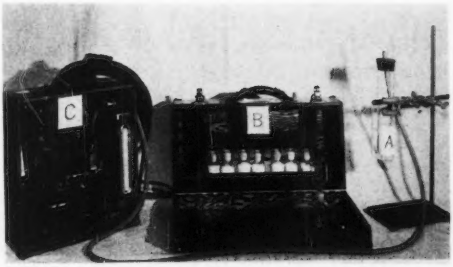

Fig. 1.
Carrying case for materials and equipment for air sampling with silica gel.

The arrangement of the aeration and combustion equipment in the laboratory is, of course a matter of individual preference. One such arrangement that has proved to be satisfactory is shown in Fig. 3.

Air entering the system is first drawn through a bed of silica gel to remove contaminants. It then passes through the silica gel in the heating tube, picking up the desorbed halogenated hydrocarbon. This air then passes through the combustion tube where the halogenated hydrocarbon undergoes pyrolysis. The products of this reaction, halogen and halogen acid, are absorbed in the solution contained in the absorber.

The optimum temperature in the combus-

TABLE II.
MATERIALS AND EQUIPMENT USED IN AERATION AND COMBUSTION

A. Two tube furnaces. Satisfactory results have been obtained from two "Multiple Unit" furnaces purchased from the Hevi Duty Electric Co., Milwaukee, Wis., as "No. 4838-101 furnaces with 1½ inch diameter by 12 inch long heating space."
B. Combustion tube. This tube may be constructed from either 9 mm I. D. quartz or "Vicor" tubing. One end of the tube is fitted with a male "Vicor" 18/9 spherical joint and the other end is fitted with a similar female joint.
C. Two Heating tubes. These tubes are constructed from 19 mm I.D. pyrex tubing. They are crimped near the exit end and a plug of pyrex wool is packed against the crimping to hold the silica gel in place. The exit end of the heating tube is fitted with a male 18/9 pyrex spherical joint, while the entrance end is fire polished.
D. Absorber. This absorber is similar to the adsorber used in air sampling and is constructed as shown in Fig. 2.
E. Air scrubber. To prevent impurities from entering the aeration apparatus, incoming air is scrubbed by passing it first through a desiccant and then through silica gel. The desiccant is present merely to prevent the silica gel from being saturated with water from room air. The volume and design of this tube is not at all critical.

tion furnace is about 900°C. "Vicor" tubing softens at higher temperatures, but quartz may be used to at least 1100°C without ill effect. No catalyst is necessary in the combustion tube, and air entering the system need not be humidified.

ANALYSIS: After combustion the halogen and halogen acid formed must be trapped and determined. Experience has shown that the nitrobenzene modification of the micro-Volhard titration[1] is ideal for this analysis. The trapping solution necessary, then, must be one which is adaptable to this procedure. One such solution which has given excellent results in the past is 1% sodium carbonate and 1% sodium formate in de-ionized water.

In practice, 25 ml of trapping solution is added to the absorber with a pipette. The pipette is used mainly as a convenience; the volume of solution may vary a few milliliters without effect. After the desorption and combustion step is complete, the contents of the absorber are transferred quantitatively to a 50 ml volumetric flask. The absorber is then washed at least three times with de-ionized water and the washes are added to the flask, and diluted to 50 ml. It is necessary to blow air through the inlet of the absorber (using the blow tube) to remove liquid beneath the sintered disk.

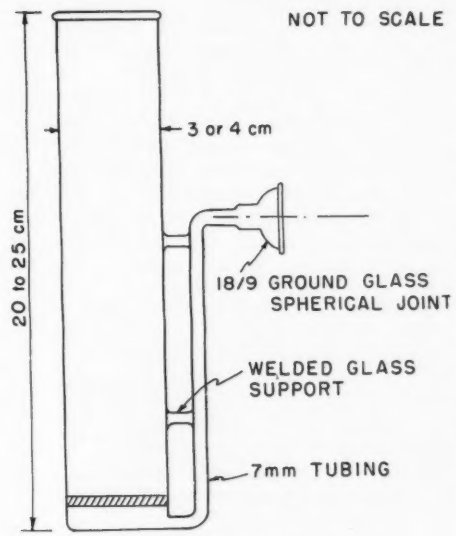

Fig. 2.
Sintered fiber glass absorber.

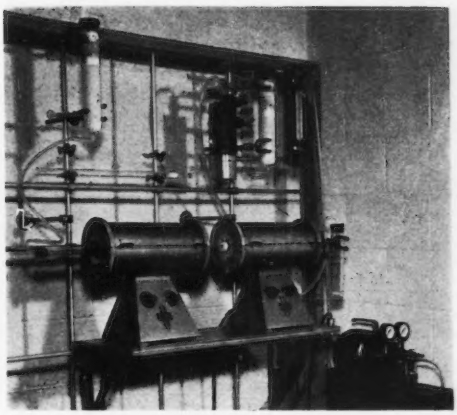

Fig. 3.
Arrangement of aeration and combustion equipment in the laboratory.

Experimental

OPTIMUM conditions for desorption and aeration of the contaminant from the gel have been determined by a series of experiments. Trichloroethylene, in amounts of 5, 10 and 20 mg was adsorbed onto 35 g samples of fresh silica gel from a dynamic constant concentration system and then desorbed under varying conditions. The concentration of trichloroethylene in the dynamic apparatus was periodically checked with the direct combustion technique which was, therefore, the standard for comparison.

Trichloroethylene was chosen for these experiments as being fairly representative of the halogenated hydrocarbons as a class. It was felt that knowledge gained about desorption conditions applicable to trichloroethylene could probably be applied to the desorption of other halogenated hydrocarbons. Experience has shown this to be true.

During these experiments the combustion furnace was held at 915°c, and no catalyst was used. The trapping solution was prepared as previously described, and the nitrobenzene modification of the micro Volhard titration was used for analysis.

The desorption conditions varied were furnace temperature, air flow rate, and length of time of desorption. Therefore, at various furnace temperatures it was possible to plot percentage recovery *vs* time of desorption for various flow rates as on Fig.

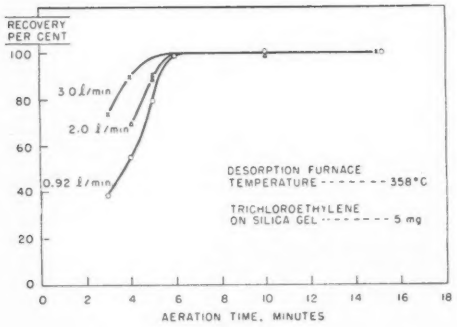

Fig. 4.
Recovery of trichloroethylene from silica gel.

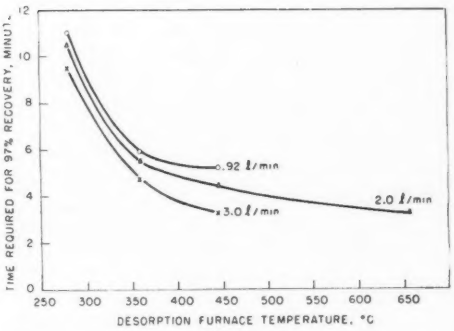

Fig. 5.
Aeration time required for 97% recovery of 5-20 mg trichloroethylene from 35 g of silica gel.

4. Each point on the graph represents the mean of at least three determinations.

The furnace temperatures used were 280°C, 358°C, 444°C, and 656°C as measured by a chromel-alumel thermocouple at the geometric center of the furnace, while the flow rates used were 0.92, 2.0 and 3.0 liters per minute. Length of time of desorption varied from 1.0 to 15.0 minutes.

From graphs such as Fig. 4, it was possible to determine the interrelation of variables which resulted in essentially complete recovery. "Essentially complete" for this purpose was defined as 97% recovery based on the amount of halogenated hydrocarbon adsorbed on the gel.

Finally, a graph was drawn which related the length of time of aeration for complete recovery to furnace temperature and air flow rate. This graph is presented as Fig. 5. The lines for 0.92 and 3.0 liters per minute were not extended to the 656°C furnace temperature because recoveries at these points were not "essentially complete." That is, at .92 liters per minute and 656°C the best recovery was about 85% while at three liters per minute and the same furnace temperature the best recovery was about 93%.

An examination of Fig. 5 shows that a furnace temperature in the range between the 350 and 450°C should be adequate for desorption, while the flow rate at these furnace temperatures may vary from .92 to 3.0 liters per minute without ill effect. Under these conditions, an aeration time of 10 minutes would certainly assure complete recovery. A 10-minute aeration is ideal because during this time the previous sample may be titrated, and also the heating tube containing the gel from the previous sample will cool enough so that the gel may be replaced in the sample bottle. Experience has shown that silica gel from which halogenated hydrocarbons have been desorbed in this manner may be used over and over again without loss of adsorption efficiency.

The technique described has been used in sampling air for many halogenated hydrocarbons, with 100% ± 10% recovery in each case. A list of those materials with which this technique has been successful is presented as Table III.

Results with one material, methyl chloride, have been anomolous, probably because it is not firmly adsorbed onto the gel. For this reason, silica gel at room temperature is not recommended for use with halogenated hydrocarbons boiling much below 0°C.

Chlorotrifluoroethylene was included in order to determine whether or not fluorine in the molecule would have an effect upon recovery. The micro Volhard titration is

TABLE III.
MATERIALS DETERMINED WITH 100± 10% RECOVERY

1.	Carbon tetrabromide, CBr_4
2.	Carbon tetrachloride, CCl_4
3.	Chlorotrifluoroethylene, $CClF:CF_2$
4.	o-Dichlorobenzene, $C_6H_4Cl_2$
5.	Ethylene dichloride, $CH_2Cl\cdot CH_2Cl$
6.	Ethylene dibromide, $CH_2Br\cdot CH_2Br$
7.	Isopropyl chloride, $CH_3CHClCH_3$
8.	Methyl Bromide, CH_3Br
9.	Methyl chloroform, CCl_3CH_3
10.	Methylene chloride, CH_2Cl_2
11.	Methylene chlorobromide, CH_2BrCl
12.	Perchloroethylene, $CCl_2:CCl_2$
13.	Trichloroethylene, $CHCl:CCl_2$
14.	Vinylidene chloride, $CCl_2:CH_2$

insensitive to fluorides and the recovery, based on chloride, was excellent. However, with this material the air flow rate during sampling must be kept at 0.5 liters per minute or below for good results.

The remainder of the materials listed on Table III were recovered with little or no difficulty. Because of this it may be concluded that the method described is a satisfactory means of determining halogenated hydrocarbons in air.

Summary

A METHOD for determining the concentration in air of halogenated hydrocarbons is described. The method involves adsorbing the air contaminant on silica gel, followed by desorbing the material from the gel with heat and aeration, cracking the halogenated hydrocarbon with heat, and absorbing the halogen and halogen acid so formed in a solution for analysis.

The method is especially suitable for sampling in areas where an explosion hazard exists, or where a source of electricity is not available. Halogenated hydrocarbons adsorbed on silica gel usually remain quantitatively absorbed for at least a week, thus permitting sampling in remote locations. Once the desorption and combustion apparatus is set up the analytical phase involving desorption and combustion of the contaminant is a simple, rapid and accurate procedure.

Various materials have been shown to be sampled with essentially complete recovery, including most of the commonly encountered chlorinated and brominated hydrocarbons.

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Radiological Safety

A FULL-TIME course in "Radiological Safety" will be given by the New York University Post-Graduate Medical School and the College of Engineering in cooperation with the U. S. Atomic Energy Commission. The course will be conducted from January 7 to January 18, 1957, with an optional laboratory course from January 21 to February 1, 1957. The course is to be repeated on a once a week schedule from January 30, 1957, to May 22, 1957. The tuition for the lecture course only is $75. Tuition for both the lecture and laboratory course is $150.00. Applications and further information are available from the Office of the Dean, Post-Graduate Medical School, 550 First Avenue, New York 16, N. Y.

AN APPRAISAL OF

Air Pollution Control Installations

BERNARD D. BLOOMFIELD
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AIR POLLUTION evaluation and control in Michigan has almost, as a course, become a function of the Michigan Department of Health's Division of Occupational Health. Despite the lack of any specific state-wide legislation (a bill was introduced and not reported out of committee during this past 1956 session) requests for assistance on air pollution matters have been directed to our Division from all imaginable sources—from local citizens, city officials, other state agencies, and the Governor's office. Also, it is not unusual to receive requests from air pollution officials in localities having ordinances, but where staff and equipment is lacking. Frequently we run studies for these cities to enable them to evaluate their problems more accurately.

Most of the air pollution studies conducted in the state are carried out by the Division of Occupational Health—essentially for evaluating existing problems and/or obtaining control equipment performance data. A few studies have been conducted by equipment manufacturers who are, of course, interested in the applicability of their product, and who, in some instances approach thoroughness in obtaining system data.

It would not be generalizing to say that much of the air cleaning equipment now being used has not been selected because of proven applicability to the specific contaminant or on the basis of a thorough engineering approach to the problem. Too often management has selected equipment on the "We'll keep our fingers crossed" basis and the results have been most unfortunate. Following are a few of the many air pollution problems that have been studied by our Division and which have involved the application of collection equipment, in some instances, with dubious success. The moral of the stories to be presented is essentially that air pollution control involves good engineering both on the part of the purchaser of air cleaning equipment and on the part of the supplier. Within a few short years, much has been learned about the theory and practice of air cleaning and this information is available. It behooves the user of air cleaning equipment not only to spend his money wisely but to have reasonable assurance that his project will be a successful one.

Electric Furnace Manufacture of Steel

THE PROPOSED expansion of the facilities of an already large manufacturer of carbon and stainless steel brought on much pressure from the neighboring community inasmuch as the air pollution problem in the area was already acute and the use of additional electric furnaces, a new blast furnace and three oxygen process vessels would make the neighborhood problem even more critical. The company assured the city council that it would install all of the control equipment necessary to meet with the provisions of the existing air pollution ordinance (0.85 pound dust per 1000 pounds flue gas) and that they would discontinue operations if this was not done to the satisfaction of the city. The expansion project included the installation of two 200-ton-capacity electric furnaces, (up until a short time ago, the largest electric furnaces in the world) a blast furnace and three oxygen process vessels which until this time have never been used in the United States. The latter process consists of charging a 35-ton-capacity vessel with scrap steel, molten blast furnace metal, limestone and burned lime. Oxygen is then blown over the surface of the molten charge with the use of water

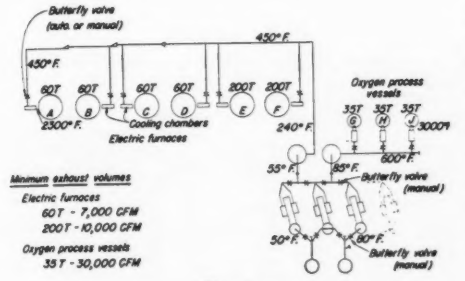

Fig. 1.
Gas cleaning system flow diagram.

jacketed lance which is projected into the mouth of the vessel and kept within a short distance from the molten metal surface. The charging period is that time required for complete oxygen blowing and large volumes of iron oxide fume are inherent to the process. Without successful hooding and exhaust, visibility in the plant would be negligible and the air pollution resulting from natural ventilation would be intolerable.

In a report of a similar oxygen process being used in Austria, it was stated that the fume had a composition of 93% Fe_2O_3 and 7% MnO, CaO and SiO_2. The particulate size range reported indicated 5% of the particulates greater than one micron in size, 45% in the range of 0.5 to one micron and 50% less than one micron in size.

Anticipating an extremely difficult fume collection problem, the company conducted an intensive investigation of fume collection equipment being used by similar industries throughout the world and decided upon the use of Thiessen disintegrators for fume collection. As is the case with collector installations where the pollutants are generated by new processes and little or no experience has been had with collection procedures, an element of chance was involved in the choice of collection equipment. The collector installation was engineered and located so that if necessary, additional equipment, possibly of another type could be added for further cleaning purposes. Fortunately, no additional equipment is necessary since the cleaning effectiveness of the system being used is equal to or surpasses that of any type of collectiion equipment now in use.

It is interesting to note also that one of the reasons for selecting the disintegrator was the fact that the system has been used successfully on ferro manganese blast furnace gas where it has consistently produced stack loadings of 0.006 grains per cubic foot of fume in a relatively low size range. Fig. 1 illustrates a line drawing of the electric furnaces, the oxygen process vessels, the connecting ductwork and also of the gas cleaning equipment. Fig. 2 illustrates the collector installation in more detail. The electric furnaces are covered with a roof which is constructed of steel and refractory brick and which connects through a water cooled elbow to what is referred to as a spark box. The elbow is fastened to the furnace roof and makes a loose connection to the spark box. The latter which is illustrated in Fig. 3 is actually a cooling and settling chamber, the cooling being done with a series of spray nozzles. The temperature of the electric furnace gases at the inlet to the

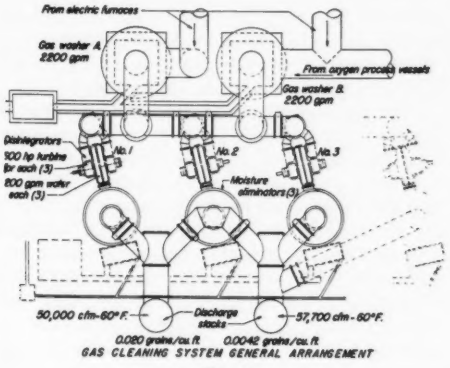

Fig. 2.
Gas cleaning system general arrangement.

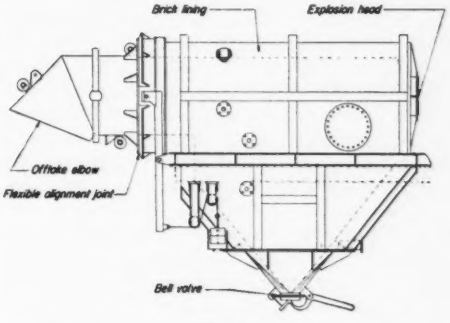

Fig. 3.
Electric furnace cooling chambers.

spark box is about 2300°F and after passing through this unit it is reduced to about 450°F. The oxygen process being run at an extremely high temperature, probably about 6500°F, emits gases which are at a temperature of 3000°F and on passing through the connecting spark boxes are reduced to about 600°F. The hoods for the oxygen process vessels are constructed of steel and refractory brick, the lower sections are water cooled, and like the electric furnace hoods, are designed so that they can be moved out of the way during maintenance.

The electric furnace hoods are elevated about six inches and turned horizontally out of position whereas the oxygen vessel hoods are slid upward at an inclined angle, allowing suitable clearance for maintenance as mentioned or for lifting a pot out of position. Following passage through the spark boxes, the total volume of gases exhausted from the electric furnaces and oxygen vessels are passed through preliminary washing equipment where an additional quantity of particulate material is removed and the temperature is reduced to about 80°F. The gas load is then passed through disintegrators which further clean the air. Next in series is a moisture eliminator from which the material passes through the exhaust stacks to the outside.

The preliminary washing units were originally designed to consume 2200 gallons per minute of river water each for purposes of wetting and collecting an appreciable portion of the iron oxide type fume contained in the air stream, particularly the larger particulates. Considerably less water was found to be required. In addition to sprays, there is a series of three gratings in each of the two towers used, each grating being packed with absorption tile for wetting purposes. A cutaway view of the washing unit is illustrated in Fig. 4.

One problem encountered with this piece of equipment to date has been the rapid wear on the side of the unit directly opposite the inlet opening. On one unit it was necessary to rebuild a four-foot section of steel outer shell which had been completely worn away and in order to eliminate this problem the water level in the washer has been raised so that there is direct impingment of the entering gases on water rather than on the side of the unit. As an indication of

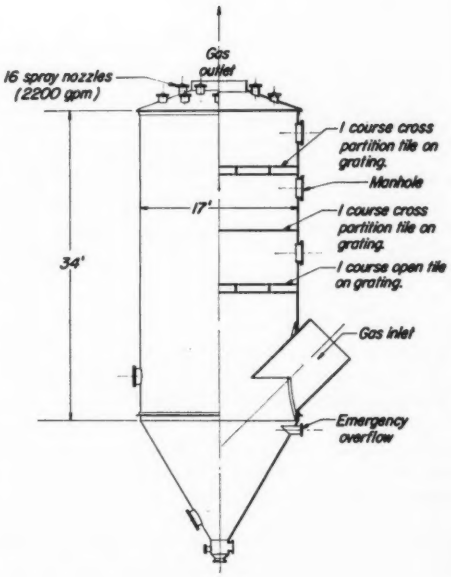

Fig. 4.
Washer gas cleaning system.

washer effectiveness, tests have indicated an initial loading of 2.8 to 19.3 grains per cubic foot at 60°F and an outlet loading of 0.94 to 1.47 grains per cubic foot at 60°F for the oxygen process.

Similar test runs on the electric furnace fume entering the washer indicates an inlet loading of 0.83 grains per cubic foot and an outlet loading of 0.40 to 0.54 grains per cubic foot both measures at 60°F. The gas stream after being split up and passed through the two preliminary washers which are in parallel is then passed through three steam turbine driven disintegrators where high efficiency cleaning takes place.

The disintegrator which is illustrated in Fig. 5 and 6 is made up of a cast iron housing, has double inlet and single discharge openings and the general appearance of a centrifugal fan. The horizontal shaft carries a central vertical disc as shown. Several concentric rows of stainless steel bars arranged parallel to the axis of rotation and extending from either side of the disc are mounted near the periphery. Attached to both side walls of the casing are stationary baskets of bars, also arranged in concentric rows and projecting between the rows of

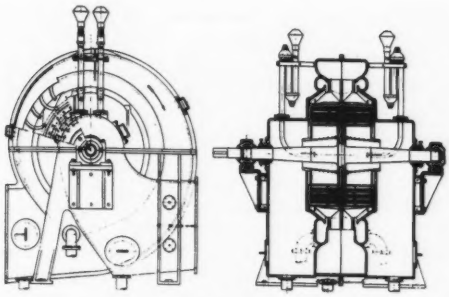

Fig. 5.
Disintegrator drawing.

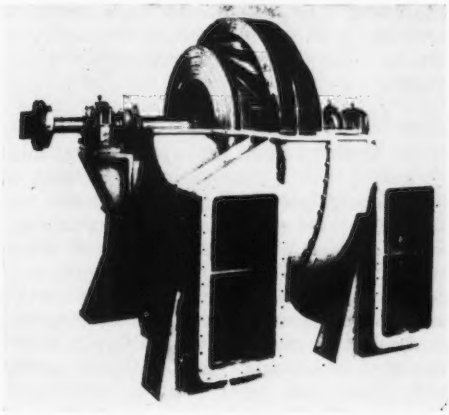

Fig. 6.
Cut-away view of disintegrator.

bars on the rotor. The water used for cleaning is gravity fed through water-sealed traps to the center of the disintegrator and by centrifugal force distributed through perforated stainless steel cones over the rotating and stationary bar system. The rotor revolves at a speed of about 720 RPM, atomizing the water and creating great agitation and turbulence. Under this violent action wetting of the dust takes place with subsequent removal.

Generally speaking the water requirements range from four to nine gallons per thousand cubic feet of gas with power requirements of from 7 to 11 HP per thousand cubic feet per minute. The rate at which water is introduced has a proportional effect on the degree of cleaning and the required power input. Similarly, cleaning effectiveness and HP required is a function

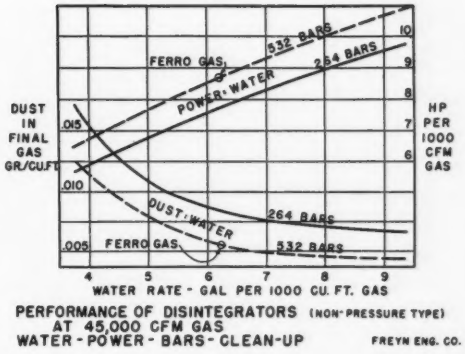

Fig. 7.
Performance of disintegrators (non-pressure type) at 45,000 CFM gas.

of the number of stationary bars used. Fig. 7 relates the degree of cleanliness in terms of dust loading with water rate, power requirements and the number of stationary bars used. The data pertains to collection of ferro manganese fume. Fig. 8 illustrates the pressure volume characteristic of the disintegrators in terms of available static pressure which can be developed.

The disintegrator has the capability of acting as a fan by virtue of fan blades which are added to the periphery of the rotor and, in the high pressure type unit, an available static of 13" of water may be developed at normal rated volume. The unit is also manufactured as a medium pressure and non-pressure type collector with smaller blades being used for the former and no blades being used on the latter equipment.

The moisture eliminator used in conjunc-

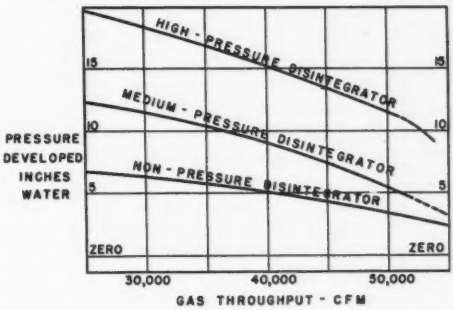

Fig. 8.
Performance of disintegrators—pressure-volume characteristics.

TABLE I.
DISINTEGRATOR PERFORMANCE DATA
STEEL MANUFACTURE
ELECTRIC FURNACE AND OXYGEN BLOWING PROCESS

	Electric furnace	Oxygen process
Dust in gas after spark box (grains per cu. ft.)	1.12	10.5
Volume of gas at 60°F. (cu. ft. per min.)	50,000	57,700
Weight of dust per ton of ingots (lbs.)	4.8	46.1
Stack loading (grains per cu. ft.)	0.020	0.0042
System collection efficiency (% on weight basis)	98.22	99.96
Fe_2O_3 in collected material (%)	50.55	75.62
Maximum system horsepower, 3 units	1,800	
Rated total capacity (cu. ft. per min.)	135,000	
C.F.M. per H.P.	75	

tion with the disintegrator presents a resistance to flow of about three inches of water at a 45,000 cfm flow rate. The moisture eliminator is essentially a rubber lined cyclone consisting of an angular duct in which is mounted a group of grooved concentric steel blades coated on both sides with vulcanized rubber. Centrifugal force and turbulent flow enables the collection of water and wetted dust particles. Table I illustrates collector study data recently determined by the manufacturer of the equipment. At the time of the study all of the gas collected from the electric furnaces was passed through one washer, one disintegrator, one moisture eliminator and through the stack to the outside whereas the gas from one oxygen process vessel was passed through one washer, two disintegrators, two moisture eliminators to the stack and outside. The inlet and outlet grain loadings are noted as are the flow rates through the collection equipment. The collection efficiencies are very high and in terms of existing ordinances throughout the country the degrees of cleanliness effected would be satisfactory.

Of particular significance is the amount of particulate material recovered per ton of ingot poured. It presents reclamation possibilities which are economically feasible and which will no doubt require a sintering process. The sintered material could then be charged into the blast furnace.

Probably the most important limitation on this type of equipment is the power requirement for operation. The total capacity of the system discussed is 135,000 cubic feet of air per minute with a net static of 13" of water being available and requiring steam turbine drivers equivalent to 1800 HP or 600 HP per disintegrator. About 150 of the 600 HP per unit is used for moving air. This is, of course, critical where power has to be purchased. In the steel plant with a blast furnace on the premises, waste gas is used for generating all of the steam and power requirements and the amount of power required for the dust collection system is relatively insignificant. Although equipment cost is relatively high, performance has been found to be reliable and consistent with maintenance factors not unusual.

Manufacture of Asphalt

THE MANUFACTURE of asphalt or bituminous concrete involves the handling of large quantities of aggregate which consists of gravel of various sizes, sand, clay, flyash fillers, limestone fillers, and other similar materials. The aggregate materials are dried in rotary kilns which are usually oil fired and are then elevated to screening equipment from where it is deposited into storage hoppers and finally, into the mixing unit where hot asphalt oil is introduced. The operations involve a variety of dust producing sources such as rotary drying, transfer points, bucket elevating, screening and mixing. By far the worst source and the greatest cause of pollution is the rotary drying operation where the discharge consists not only of products of combustion, but also fines which are picked up as a result of the necessary air movement through the dryer. Those operations other than the drying are referred to by the asphalt plant operators as "fugitive" operations. In some instances, two separate local exhaust ventilation systems including two dust collectors are used for control of the drying and "fugitive" dust operations. Despite the fact that the ventilation and dust collection problems are neither difficult nor unusual in the ordinary plant, poor exhaust system design and the misapplication of the dust collection equipment is common with a resulting waste of time, money and effort. That the average asphalt plant operator is not well-versed on

dust collection equipment is readily indicated by some of the installations we have observed.

To avoid over-simplification of this matter of local exhaust ventilation and air cleaning in this type plant, it should be mentioned that the job has to be well engineered and, of course, suited to the type of operations being conducted. Furthermore, there are several variations in asphalt manufacture which present different air cleaning problems; one such problem is created by what is known as two-stage drying of the aggregate with intermittent storage. In other words, the material is dried to a certain point by one drying unit, stored in bins and brought to a greater degree of dryness at a later date as required. It has been found that the second stage of drying results in large quantities of extremely fine material being emitted with fabric collection or the equivalent being necessary. This problem of two stage drying and the application of successful dust collection equipment is more thoroughly discussed in a paper entitled "The Visual Clarity in Kiln Discharge Gases," by S. C. Hayes, N. M. McGrane, and D. B. Perlis, in the November, 1955, issue of the *Journal of Air Pollution Control Association.*

As a result of neighborhood complaints, this Division was requested to study the asphalt plant operations of one of the largest producers in the State. The owner and manager of the plant fully realized the significance of the problem, was interested in improved relations with his neighbors and indicated that he had been investigating the various types of dust collection equipment with little or no success as to the most applicable equipment.

The local exhaust ventilation at all of the operations was poor or inoperative. An attempt had been made to completely enclose the screening equipment as a means of minimizing dust dissemination rather than applying a local exhaust take off and there was considerable reluctance toward the application of local exhaust ventilation in place of natural draft at the bucket elevator, this being due to the thought that an exhaust take off could not possibly serve to remove all of the steam in the unit. Fig. 9 illustrates the non-functioning screen enclosure. When requested, we make ventilation service available to industry and in the case of this asphalt plant, management requested a completely new ventilation design. We submitted a detailed ventilation layout together with a representative list of collector manufacturers who we thought should be contacted. We also suggested that in specifying collector performance some guarantee be obtained from the manufacturer so that if the collector was unsatisfactory in terms of performance, it would not be a total loss.

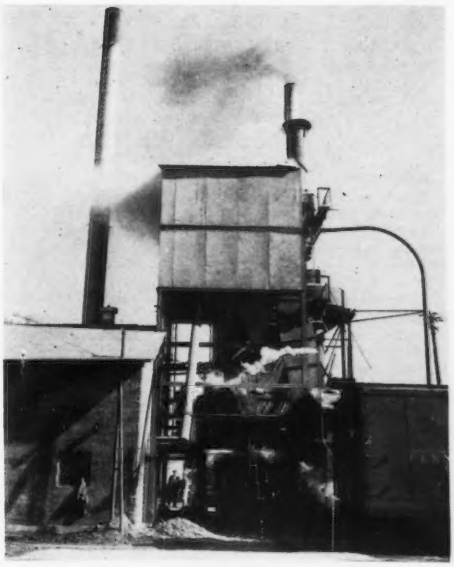

Fig. 9.
Excessive dusting from screen enclosure—asphalt plant.

A fabric-type collector was selected for all of the "fugitive" dust operations and two dry centrifugal units were selected for controlling the effluent of the rotary dryer. Although we considered wet collection to be the most satisfactory collection procedure, plant management was concerned with the amount of water required and the waste disposal problem and decided on dry centrifugal collectors. The fabric collector has been most satisfactory, both in terms of collection efficiency and maintenance. The dry centrifugal units used on the rotary dryer consisted of a single cone high efficiency type cyclone which was in use at the plant site, followed by a new multiclone-type

TABLE II.
COLLECTOR PERFORMANCE STUDY—AIR FLOW DATA
ASPHALT PLANT

	Bag type collector	Sirocco style cyclone	Multi-cyclone
Duct sizes, inches			
Inlet	23" D	32x32	24x25
Outlet	23" D	24x25	34" D
Duct area, square feet			
Inlet	2.89	7.02	4.16
Outlet	2.89	4.16	6.30
Air velocity, feet per min.			
Inlet, at operating temp.	2350	1985	3480
Outlet, at operating temp.	2123	3480	2500
Operating temp., °F.			
Inlet	202	225	225
Outlet	142	225	206
Air flow rate, cfm			
Inlet, at operating temp.	6790	14100	14500
Outlet, at operating temp.	6130	14500	15800
Inlet, at 70°F	5430	10920	11200
Outlet, at 70°F	5400	11200	12600
Static pressure, inches water			
Inlet, at 70°F	2.58	0.36	3.94
Outlet, at 70°F	4.82	3.94	6.87
Collector resistance, inches water	2.24	3.58	2.93

TABLE III.
COLLECTOR PERFORMANCE STUDY—EFFICIENCY DATA
ASPHALT PLANT

Collector description	Sample No.	Sampling time (minutes)	Total weight (grains per cu. foot)	Efficiency on weight basis (%)
Bag type	In-1	3	12.27	99.8
	Out-1	3	0.052	
	In-2	3	14.94	99.8
	Out-2	3	0.043	
	In-3	4	——	——
	Out-3	4	0.036	
Sirocco type cyclone	In-4	2	6.54	70.4
	Out-4	2	1.94	
	In-5	3.5	7.37	81.3
	Out-5	3.5	1.38	
Multi-cyclone	In-6	3.4	1.61	29.2
	Out-6	3	1.14	
	In-7	3	1.96	47.9
	Out-7	3	1.02	

collector which was installed in series with the single cone unit. As is indicated in our study data sheet, Tables II and III, the fabric collector handled about 6500 cubic feet of air per minute with an inlet dust loading of about 13 grains per cubic foot and an outlet loading of about 0.04 grains per cubic foot. The collection efficiency on a total weight basis was found to be 99.8%. The two dry collectors hooked up in series and applied to the rotary dryer represented a misapplication of equipment and the expected poor collection effectiveness. A

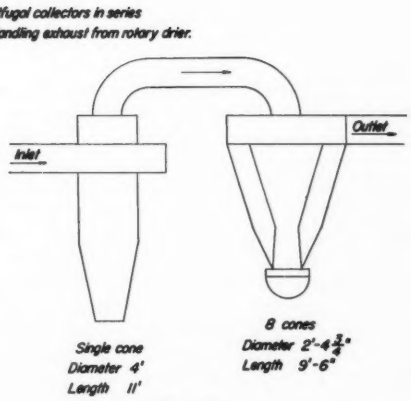

Fig. 10.
Asphalt plant collector study—sampling locations, centrifugal collectors.

total of 14,500 cubic feet of air per minute was exhausted through the centrifugal collectors at a temperature of 225°F with a resulting collection efficiency of from 70.4 to 80.3% in the single cone type unit and from 29.2 to 47.9% in the multiclone unit which was second in series. The old single cone collector is a fine precleaner having a collection efficiency which is about equal to that of the multiclone unit. Having removed the bulk of the larger dust particulates from the exhaust stream a more difficult cleaning job was imposed on the second collector with a resulting low collection efficiency.

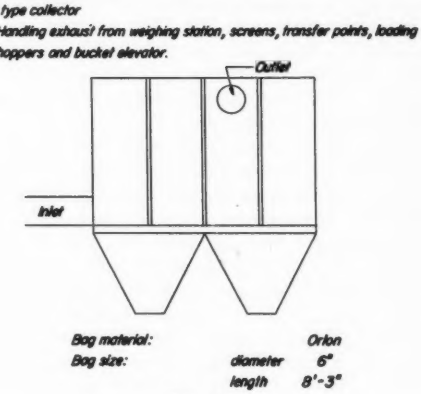

Fig. 11.
Asphalt plant collector study—sampling locations, fabric collector.

The pressure drop through the two units was, of course, the sum of the individual resistances and the overall efficiency of the system was 84.5% with a final stack loading of 1.02 to 1.04 grains per cubic foot. Figs. 10 and 11 illustrate the collectors, connecting ductwork and sampling locations.

In an effort to improve control of the rotary drying operation, the new multiclone-type collector has been removed and is to be used as a precleaner in a portable asphalt plant. A wet-type centrifugal collector is presently being installed in the place of the multiclone and is to be tested by this Division following the start-up of spring operations when asphalt plant operations are to be resumed. It should be mentioned that the new wet centrifugal collector has been purchased on a guaranteed performance basis.

Another asphalt plant, located in a rural area with very few neighbors found it necessary to install collection equipment in order to satisfy the few individuals who complained of the stack effluent. Our Division heard of the problem indirectly since no formal complaints were submitted to us and upon investigation learned that a multiclone collector of the small diameter tube type had already been ordered and was soon to be installed. A skimmer-precleaner was already in use and was to be left in use for precleaning purposes. The new air cleaning equipment was studied soon after the installation was completed (Fig. 12) and indicated a collection efficiency ranging from 68 to 84% with an effluent grain loading of from 0.27 to 0.58 grains per cubic feet as is shown in Table IV. The collector was handling 22,000 cubic feet of air per minute and presented a resistance of 8″ of water.

Subsequent inquiry concerning the performance of this unit indicated that the plant operators experienced considerable difficulty due to condensation within the collector tubes with expected plugging of the tubes. Fortunately, the air pollution problem did not persist inasmuch as the plant was portable in nature and was soon relocated at another job site several hundred miles away.

In the above studies, all of the samples were collected isokinetically using the sampling method outlined in the A.S.M.E. Power Test Code 21 (1941), Test Code for Dust Separating Apparatus. Briefly, the method consists of aspirating at a velocity equal to the duct velocity, the dust laden air at a measured rate through a nozzle facing directly into the air stream. The nozzle-probe apparatus used for duct sampling, as illustrated in Fig. 13, was connected directly to two Greenburg-Smith impingers and exhausted at the rate of one cubic foot of air per minute. Suction was provided with

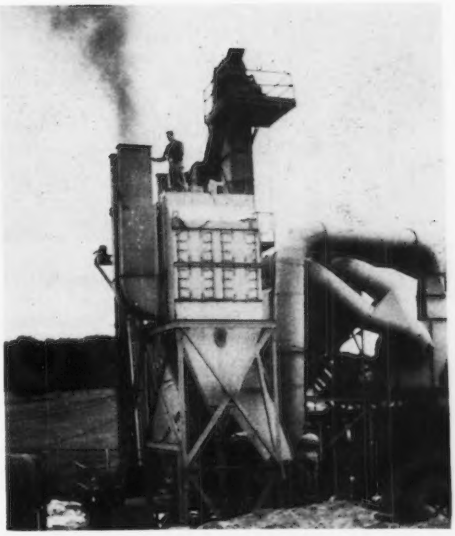

Fig. 12.
Asphalt plant B—centrifugal collector.

TABLE IV.
COLLECTOR PERFORMANCE STUDY
ASPHALT PLANT B

I. Air flow data			
A. Inlet duct velocity, feet per minute			4,786
B. Inlet duct diameter, inches			29
C. Inlet air flow rate, cubic feet per minute at 150°F.			22,000
D. Inlet air flow rate, cubic feet per minute at 150°F.			19,130
E. Collector resistance, inches of water			8
II. Collector performance characteristics			
A. Sample number	Location	Weight (grains per cubic foot)	Collection[1] efficiency percent
In-1	Inlet	2.44	
Out-1	Outlet	0.54	77
In-2	Inlet	1.79	
Out-2	Outlet	0.58	68
In-3	Inlet	1.63	
Out-3	Outlet	0.29	83
In-4	Inlet	1.65	
Out-4	Outlet	0.27	84

[1] Weight basis

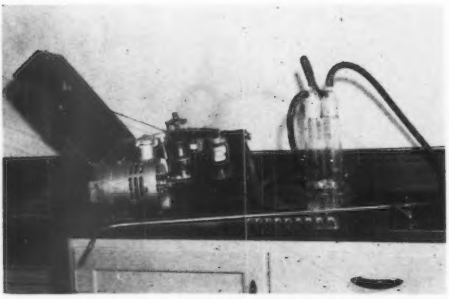

Fig. 13.
Stack sampling apparatus.

pumps previously calibrated to deliver the required flow rate through the sampling equipment. At the completion of each sampling run, the nozzle-probe apparatus and the connecting rubber tubing were washed with distilled water into the proper impinger. This last step was necessary in order to free the particulate material which adhered to the inner walls of the sampling probe and connecting tubing.

Super Phosphate Fertilizer Manufacture

THERE ARE several super phosphate fertilizer plants located in the state and air pollution problems are common to all of them. The basic process in the manufacture of super phosphate fertilizer is the acidulation of phosphate rock in the so-called mixing den and following this, the batch charge is dropped to the floor below into a bin where it cures for a time period ranging from hours to days. It is usually blasted and removed during night shift operations and subsequently stored for mixing with various quantities of nitrogen and potassium-bearing salts. Basic mixing equipment is used for arriving at the final blend and the finished products are usually stored in great piles indoors and allowed to cure. When ready for bagging the final mix is sized and bagged. The resulting product is known as dust or powder-type super phosphate fertilizer.

Within recent years this process has been modified to produce what is referred to as the granulated type of fertilizer. This consists of granulates rather than dust, the theory being that when deposited in the soil there is gradual solution in soil moisture and a more effective distribution of the nutrient materials. In the process of producing granulated fertilizer, triple super phosphate, super phosphate, both of which are made by acidulating phosphate rock, are reacted with 60° Baumé sulfuric acid, potassium chloride, ammonium sulphate, anhydrous ammonia, ammonium nitrate and water. The reaction is exothermic and gives rise to an effluent product consisting of particulate matter and ammonium chloride.

The sources of air pollution in fertilizer plants utilizing either or both of the processes described above are (1) all the bulk handling equipment including payloaders, (2) the conveyor belt transfer points, (3) pulverizing equipment, (4) screening equipment, (5) blending equipment, and (6) the vast heaps of different fertilizer components as well as the finished fertilizer blends which are piled throughout the plant. The combination of a stiff breeze and open doors usually results in a steady cloud of dust being emitted to the neighborhood. This condition is further aggravated by the odor of ammonia and the irritating and dense cloud of ammonium chloride which is given off by the granulating process plants. Local exhaust ventilation can be successfully applied to all of the materials handling equipment but this is not commonly done. This results in excessively high dust concentrations within the plant and as mentioned, problems on the outside due to natural ventilation. The acidulating process where phosphate rock is mixed with sulphuric acid, emits silicic acid, hydrofluoric acid and particulate matter which can be readily controlled with the use of wet collection equipment. High and low pressure type water spray collectors are particularly effective in controlling the effluent from the acidulating process and all or part of the spray water is usually recirculated.

The collection of ammonium chloride which is a sub-micron aerosol presents a more difficult problem. We know of plants which have used or are using for collection, high pressure fog acid absorption in packed towers and a combination of wet fibre and high and low pressure water spray as a means of collecting ammonium chloride. At best, all of these installations can be described as being only partially successful. In all cases the white plume of ammonium

chloride is readily seen emerging from the exhaust stack and its rapid settlement within the vicinity of the plant is obvious. It is not unusual to see those areas in the path of the prevailing wind completely blanketed by a dense fog of ammonium chloride and it goes without saying that the air pollution problem created is severe.

In one area, management of a newly projected fertilizer plant actually submitted a letter to the township board assuring them that no air pollution problems would be created since all of the operations would be effectively controlled. This letter was prepared before plans were made to produce the granulated fertilizer product as is now being done. Since that time, cognizant of their assurances to the township, they have tried two basic types of collectors without success. High pressure fog spray having been tried unsuccessfully in one of the company's other plants and being used with little success in a competitor's plant was not considered for the new installation. Instead an absorption tower packed with Raschig rings and utilizing sulphuric acid as a collecting medium was installed. The ammonium chloride plume persisted. A consultant submitted plans for replacing the absorption tower with a combination high and low pressure water spray and wet fibre filtration unit. The latter installation was completed at a cost of about $15,000 (based on handling 3500 to 4000 cfm) and since that time an additional $5000 has been spent in modifying the equipment. The effectiveness of collection is still not satisfactory since a dense plume is still visible and the neighborhood is accordingly affected. Many difficulties were encountered with the use of the specially designed wet collector. Successful performance which is based on satisfactory wetting of the ammonium chloride going through the unit was not attained.

The unit appeared to incorporate several means of wetting ammonium chloride including perforated metal filters, high pressure fog spray, low pressure spray, Dynel fibre beds and Saran fibre beds. The collector designed to handle 3500 to 4000 cfm at about 100°F was constructed of wood, is about seven-and-a-half feet in diameter and about eight feet high. The entering material first passes through the offset perforated metal filters which have high pressure sprays directed at the outlet side and following this, pass successively through a two-inch bed of five micron Dynel, a high pressure spray zone, a three-inch bed of 29 micron Saran fibre and finally a two-and-a-half-inch bed of Dynel fibre. A portion of the water is recirculated and another portion is used in the fertilizer manufacture. The resistance of the unit is estimated to be nine inches of water.

Many performance difficulties were encountered and at the present time it is being used out of necessity while management considers changing the basic process from a batch operation to a continuous operation. The change would result in considerably less ammonia and sulphuric acid being required, and considerably less ammonium chloride being produced. They consider the present wet collector to be impractical in terms of maintenance and satisfactory collection.

Originally perforated Saran sheet stock was used for sandwiching the Dynel and Saran fibre beds. It soon became obvious that channeling was developing in line with the holes and in an attempt to improve this condition, aluminum screening was used. From the point of view of maintenance and rebuilding the fibre beds, the aluminum was much more satisfactory. The perforated metal filter clogged and required cleaning once per shift despite the fact that sprays were directed at it. The latter do help. The clogging naturally results in a rapid build up of resistance to air flow and the performance of the unit is affected accordingly. It has been observed that discontinuing the use of the Nevaclog filter results in totally unsatisfactory collection and that the metal filter media is of considerable value. The Dynel and Saran fibre beds help in wetting and of course present resistance to air flow but it is difficult to estimate their value in this collection unit inasmuch as channeling readily develops and frequent maintenance is required. Within a matter of two weeks time the Dynel becomes a soggy, muddy mess which cannot be economically regenerated and has to be replaced. The company actually tried sending the Dynel to a commercial laundry where it was cleaned and then sent out for carding. This was an expensive procedure and had to be discontinued. The Saran fibre lasts about two months before it has to be replaced.

Plant management has been extremely sensitive to neighborhood complaints and has instituted the procedure of shutting down the offending operation when the wind affects the surrounding residential area. On several occasions when production was urgently needed, they took to desperate measures. In one case they added sodium hydroxide to the water supply attempting alkaline absorption. The result was that the caustic readily ate through the aluminum screening material used for sandwiching the fibre beds. The resulting mess can be readily imagined.

On another occasion they tried using detergent in the water supply to the collector, but did not use too much discretion in the amount of detergent added with the result that they had an uncontrollable quantity of foam throughout that area of the plant where the collector was installed.

This case history is presented for the purpose of indicating not only that ammonium chloride is extremely difficult material to collect and that no suitable commercial collector appears to be available, but also that unfortunate results are sometimes obtained with original collector designs which are not based on experimentation. On the other hand management was faced with a dilemma in that they had to manufacture granulated fertilizer, which results in the emanation of large quantities of ammonium chloride and a high pressure fog spray system which was designed specifically for the process in another of their plants was unsuccessful. Absorption in the packed tower with sulphuric acid was similarly of doubtful value and something had to be done. They decided to take a chance on the water spray-fibre bed collector and it did not work out according to expectations.

The term air pollution control is as common as the word production at any of the three plants discussed and not necessarily by choice. Many thousands of dollars have been spent on collection equipment and engineering and with the exception of the steel plant, the results have not been too encouraging.

There is much we don't know about air pollution control but with so much basic data already available, there is little reason for mis-application on the more common operations. It's time to use one of the industrial hygienist's approaches to a hazardous operation—namely, substitution. Let us substitute engineering for guesswork.

Air Pollution Handbook

THE McGRAW-HILL Book Company has recently published a handbook on causes, effects and abatement of air pollution. The three editors, PAUL L. MAGILL, FRANCIS R. HOLDEN, and CHARLES E. ACKLEY, are staff members of the Stanford Research Institute. Topics include: city planning and industrial plant location; chemistry and physics of contaminated atmospheres; effects of meteorology; effects on humans, farm animals and vegetation; sampling procedures; analytical and experimental test methods; abatement equipment and processes; and a review of basic legal considerations. Inquiries may be directed to McGraw-Hill Book Company, Industrial and Business Book Information Service, 327 West 41st Street, New York 36, N. Y.

HYGIENIC GUIDE SERIES

HYDRAZINE

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): one part of vapor per million parts of air, by volume (ppm).[1]

(1) *Basis for Recommendation:* Toxicological observations on animals.[5,8,9]

B. SEVERITY OF HAZARD:

(1) *Health*: High, for both chronic and acute exposures.[5,8] Produces dermatitis. Absorbable through the skin.[3] Highly irritating; has a severely corrosive effect on the skin.[6] Minimal systemic symptoms, usually delayed: muscle tremors, weakness and vomiting. Acute symptoms: excitement, convulsions, cyanosis and blood pressure drop.[9] May cause permanent corneal opacity.[2]

(2) *Fire*: Severe.[11] Flash point (and fire point) (open cup): 52.2°C (126°F). Explosive limits: 4.7 (exists at 40°C) - 100% by volume. Reacts exothermically and violently with iron oxides, molybdenum oxides, "316" stainless steel, and oxidizing agents.

C. SHORT EXPOSURE TOLERANCE: Unknown.

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Rats exposed to more than 100 ppm for ½ hour or longer showed significant mortality from pulmonary edema before 14 days.[5]

II. Significant Properties

Colorless liquid (white crystals) having an ammoniacal, fishy, or amine-like odor.

Chemical formula:	H_2NNH_2
Molecular weight:	32.05
Specific gravity:	1.01 (15°C)
Boiling point:	113.5°C
Melting point:	1.4°C
Relative vapor density:	1.11 (air = 1)
Vapor pressure:	10.4 mm (20°C)
Odor threshold:	3-4 ppm[8]
Solubility:	In water and alcohol
At 25°C and 760 mm Hg,	
1 ppm:	0.00131 mg/liter
1 mg/liter:	764 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: Powerful reducing agent in chemical reactions; used in chemical synthesis. Propellant fuel, either alone or with nitric acid, hydrogen peroxide, or oxygen. Added to boiler water as scavenging agent for oxygen. Hydrazine salts used as fluxes in soft soldering and aluminum soldering. Compounds used as blowing agents in plastic and rubber foams.

B. EVALUATION OF EXPOSURE:

(1) *Instrumentation*: A recently developed method, using electrical conductivity measurements,[7] is suggested.

(2) *Chemical*: Collection of vapors in an all-glass device containing either standard sulfuric acid, phosphomolybic acid, or acidified water, and subsequent determination by titration,[5] colorimetry,[5] or potentiometry,[8] respectively. A colorimetric method using semicarbazine is also satisfactory.[10]

C. RECOMMENDED CONTROL PROCEDURES:[2,12]

(1) Enclose all processes wherever possible. Provide open processes with ventilation.

(2) Use rubber protective clothing and eye protective devices.

(3) Do not enter closed space containing hydrazine liquid or vapor without suitable respiratory and eye protection.

(4) Avoid contact of material with oxidizing agents, iron oxides, copper oxides, molybdenum oxides, and "316" stainless steel.

(5) Provide inert gas blanket above hydrazine in closed vessels.
(6) Provide water sprays on vessels to reduce temperature rise.
(7) Assume all reaction products unstable.
(8) Provide emergency showers and eye baths in workroom.
(9) Wash affected parts thoroughly after skin contact; remove clothes immediately after spillage.

IV. Specific Procedures

A. FIRST AID: Convulsive symptoms may be controlled by barbiturates. Burns should be treated as alkali or thermal burns, following copious washing with water.[9]

B. BIOCHEMICAL ASSAY: Urinary determinations may be of value to verify exposure. The "pyridyl" test of Prescott, *et al*[11] is preferred. Protein in the urine is indicative of kidney damage.[9]

C. SPECIAL MEDICAL PROCEDURES: Watch for convulsive symptoms, excitement, and precipitous drop of blood pressure. Kidney damage may be extensive. Sodium Pyruvate has been found effective in reducing symptoms in animals,[4] but has failed to have beneficial effects in human poisoning. Treatment should be directed toward restoring kidney and liver functions.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. Ind. Health*, 14:187, 1956.
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CARBON DISULFIDE (Carbon Bisulfide)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 20 parts of vapor per million parts of air, by volume (ppm).[1]

(1) *Basis for Recommendation*: Animal experimentation and observation of humans.

B. SEVERITY OF HAZARDS:

(1) *Health*: High, for both acute and chronic exposures. Acute exposures produce typical symptoms of narcosis. Chronic exposures may result in permanent disability, chiefly to the nervous system,[5,7] and in atherosclerotic tendencies.[8] Severe or prolonged skin contact may cause dermatitis. Entrapment of CS_2 under rubber gloves may cause severe burns.

(2) *Fire*: High. Explosive limits are 1.0-50.0% by volume. Flash point is -30°C (-22°F) (closed cup). Ignition temperature is 100°C (212°F).

C. SHORT EXPOSURE TOLERANCE: Symptoms begin after a few hours of exposure to 320-380 ppm. Severe symptoms and unconsciousness may occur within half an hour at 1,100 ppm.[2]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 4,815 ppm fatal in one-half hour.[3]

II. Significant Properties

Heavy liquid, colorless, and with faint ethereal odor when pure. Turns yellow when exposed to light. Commercial grades usually have a strong sulfurous odor.

Chemical formula:	CS_2
Molecular weight:	76.13
Specific gravity:	1.26 (20°/4°C)
Boiling point:	46.3°C
Vapor pressure:	298 mm Hg at 20°C
Vapor density:	2.63 (air = 1)
At 25°C and 760 mm Hg,	
1 ppm:	0.00312 mg/liter
1 mg/liter:	321 ppm
Odor threshold:	1.2 ppm[6]
Solubility:	In alcohol, ether and benzene; not in water.

III. Industrial Hygiene Practice

A. RECOGNITION: By its odor. Used industrially in viscose rayon process and solvent for rubber, oils, resins, waxes and phosphorus. Used as a grain fumigant and as a chemical intermediate.

B. EVALUATION OF EXPOSURES:

(1) *Chemical method*: Colorimetrically, as copper ethanol dithiocarbamate[9] or by a variation of the Xanthate method.[4]

C. RECOMMENDED CONTROL PROCEDURES: Mantain workroom atmospheres below 20 ppm by means of temperature control, process enclosure and/or ventilation. Avoid skin contact of liquid and vapor. Use suitable personal protective equipment as required.

IV. Specific Procedures

A. FIRST AID: Transfer patient promptly to a well-ventilated location and remove contaminated clothing. Summon medical assistance. Keep patient warm and at rest. Artificial respiration should be promptly initiated if patient has stopped breathing. Oxygen may be given if readily available.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES: Exclude individuals with abnormal neurological findings, sub-normal mentality, alcoholism, abnormal vascular findings or a history of gastro-intestinal disorders. Abnormal findings on a periodic physical examination may be sufficient reason for a job transfer involving non-exposure, either on a temporary or permanent basis. Alternation between exposure and non-exposure jobs may prevent chronic poisoning.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. Ind. Health*, 14:187, 1956.
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1,2—DICHLOROETHANE (Ethylene Dichloride)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 100 parts of vapor per million parts of air, by volume (ppm).[1]

(1) Basis for Recommendation: Toxicologic observations on animals.[2,7,10]

B. SEVERITY OF HAZARDS:

(1) *Health*: Moderate, for both acute and chronic exposures. In higher concentration it exerts a depressant action on the central nervous system and varying degrees of narcosis may result. Respiratory tract irritation would be associated with such concentrations. Lower concentrations for longer periods of time may cause damage to the liver, kidneys and adrenal glands. Corneal opacity observed in dogs has not been observed in other species or in humans.[7] Skin contact should be avoided—it may cause dermatitis.

(2) *Fire*: Moderate. Explosive limits are 6.2-15.9% by volume. Flash point is 18.3°C (65°F), open cup. Ignition temperature is 413°C (775°F).

C. SHORT EXPOSURE TOLERANCE: Guinea pigs died with two seven-hour exposures at 1000 ppm.[7] No adverse effects on rats were noted in 0.1 hour at 12,000 ppm but half of the animals died in 0.53 hours at this concentration.[10] 2,000-10,000 ppm may cause anesthesia.[4]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 100,000-200,000 ppm.[2] Short exposure above 10,000 ppm may be dangerous.[5]

II. Significant Properties

Ethylene dichloride is a clear, colorless liquid.

Chemical formula: CH_2ClCH_2Cl
Molecular weight: 98.97
Specific gravity: 1.253 at 20°/4°C
Boiling point: 83.5°C

Vapor pressure:	62 mm Hg at 20°C
Vapor density:	3.34 (air = 1)
Odor:	Chloroform-like
Odor threshold:	6.3 ppm[9]
Solubility:	Water: 0.9 parts/100 at 0°C Soluble in alcohol and ether.
At 25°C and 760 mm Hg,	
1 ppm of vapor:	0.00397 mg/liter
1 mg/liter of vapor:	252 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: Used as a solvent, alone and in mixtures, for fats, resins, certain plastics and for paint removing. Widely used as a fumigant[8] and chemical intermediate.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Automatic sampling and analysis by Davis Halide meter (Davis Emergency Equipment Co., Newark, N. J.), or other combustion-type meters, suitably calibrated.

(2) *Chemical Method*: Collection in either isopropyl alcohol or on silica gel, with subsequent hydrolysis and determination of chloride content.[3] The method is general for halogenated hydrocarbons and is not specific. Combustion, followed by absorption and titration, may also be used. Mass spectrometry is an alternate method.[6]

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheres below 100 ppm, by means of temperature control, process enclosure, and/or ventilation. Avoid skin contact. Use suitable personal protective equipment as required.

IV. Specific Procedures

A. FIRST AID: Remove promptly to a well-ventilated location. Summon medical assistance. Keep patient warm and at rest. Artificial respiration should be initiated promptly if breathing has ceased. Oxygen inhalation may be helpful.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES: As in the case of other chlorinated solvents, persons with definite liver, renal, or cardiac disease should not be placed at work where a hazard of major acute exposure exists or where there may be substantial repeated exposures. Alcoholics, or those known by experience to be unusually susceptible, should also be excluded. Personnel who have had large over-exposures or anesthesia should be followed carefully for abnormalities in liver, cardiac, or renal function.

V. Literature References

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METHYLENE DICHLORIDE (Dichloromethane, Methylene Chloride)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 500 parts of vapor per million parts of air, by volume (ppm).[1]

(1) *Basis for Recommendation*: Toxicologic observations on animals.

B. SEVERITY OF HAZARDS:

(1) *Health*: Moderate, for acute; low, for chronic exposures. In higher concentrations it has a narcotic effect. Prolonged exposure to concentrations high enough to produce mild narcosis resulted in some liver damage to animals.[7] Lower concentrations caused no definite effects, although blood changes have been reported in exposed workers.[8] Skin irritation may result.

(2) *Fire*: None, but decomposition products are irritant and toxic.

C. SHORT EXPOSURE TOLERANCE: Light narcosis was induced in animals by 8,700 to 10,000 ppm.[7] 2,000-10,000 ppm may cause anesthesia in humans.[4]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown. Dogs exposed to 40,000 ppm succumbed after one to four hours.[9] Short exposures above 10,000 ppm may be dangerous to humans.[5]

II. Significant Properties

Colorless, highly volatile liquid.

Chemical formula:	CH_2Cl_2
Molecular weight:	84.94
Specific gravity:	1.336
Boiling point:	40.1°C
Vapor pressure:	380 mm Hg at 20°C
Vapor density:	2.95 (air = 1)
Odor:	Sweetish, like chloroform
Solubility:	In water, 2%. Miscible with alcohol, ether, and most organic solvents.
At 25°C and 760 mm Hg,	
1 ppm of vapor:	0.00349 mg/liter
1 mg/liter:	286 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: By its odor. Used as a solvent, especially in paint removers; also as a refrigerant.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Automatic sampling and analysis by Davis Halide meter (Davis Emergency Equipment Co., Newark, N. J.), or similar combustion-type apparatus, suitably calibrated. Not specific for methylene dichloride.

(2) *Chemical*: Absorption on silica gel, followed by extraction with secondary butyl alcohol and hydrolysis with metallic sodium.[2] Other halogenated hydrocarbons interfere, unless separated. Mass spectrometry may be used.[6]

C. RECOMMENDED CONTROL PROCEDURES: Because of its high volatility, methylene dichloride should be handled in closed systems as much as possible. When used as a solvent, as in paint removing, good general ventilation is usually adequate.

IV. Specific Procedures

A. FIRST AID: Remove patient from exposure, and call a physician. If victim is unconscious, oxygen therapy may be indicated.

B. BIOCHEMICAL ASSAY: None available.

C. SPECIAL MEDICAL PROCEDURE: As in the case of other chlorinated solvents, persons with definite liver, renal, or cardiac disease should not be placed at work where a hazard of major acute exposures exist, or where there may be substantial repeated exposures.

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NICKEL CARBONYL

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 0.001 parts of vapor per million parts of air, by volume (ppm).[2]

(1) *Basis for Recommendation*: Animal experimentation[3,7,12] and carcinogenic potential for man.

B. SEVERITY OF HAZARD:

(1) *Health*: Acute—extra hazardous; chronic—unknown, (may be carcinogenic). Tolerance may be developed after exposure to subacute doses.[7] Some evidence of carcinogenicity of lung and paranasal sinuses (22 year latent period).[6,11] Possible allergic dermatitis.[4] Acute toxicity appears to

vary directly as the ⅔ power of the body weight of the experimental animal.[7] Immediate symptoms are giddiness, headache, nausea. After 12-18 hours dyspnea and cyanosis with typical symptoms of chemical pneumonitis. If the symptoms will clear, this should start after sixth day. Nickel appears in urine within 48 hours after exposure.[4]

(2) *Fire*: Severe; may decompose violently in air at 60°C (140°F).[10]

C. SHORT EXPOSURE TOLERANCE: Thirty minute exposures of mice, rats, and cats caused death at 7 ppm, 29 ppm, and 178 ppm, respectively.[7]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown.

II. Significant Properties

Clear, colorless (or yellow)[12] liquid.

Chemical formula:	$Ni(CO)_4$
Molecular weight:	170.7
Specific gravity:	1.32 (17/4°C)
Boiling point:	43°C (109.5°F)
Relative density of vapor:	5.9 (Air = 1)
Vapor pressure:	380 mm of Hg at 25°C
At 25°C and 760 mm Hg,	
1 ppm:	0.0069 mg/1
1 mg/liter:	143 ppm
Odor threshold:	1-3 ppm[8]
Solubility:	Soluble in nitric acid, aqua regia, and most organic solvents; insoluble in dilute acids, alkalis; slightly soluble in water (200 ppm)

III. Industrial Hygiene Practice

A. RECOGNITION: Used mainly in metallurgy of pure nickel (Mond Process), and production of nickel powder; also, in some chemical syntheses.

B. EVALUATION OF EXPOSURE:

(1) *Instrumentation*: A direct reading recorder for use in the range 0.05 to 4 ppm has been described.[9]

(2) *Chemical*: Collection in dilute sulfuric acid, followed by spectrophotometry, using sodium diethyldithiocarbamate.[1] A blue alcohol flame is reported to turn yellow at 2.5 ppm,[12] and at 12 ppm.[4]

C. RECOMMENDED CONTROL PROCEDURES:

(1) All handling should be done in well ventilated hoods. *Extreme Care* is necessary to avoid exposure.

(2) Closed process systems should be used whenever possible, and tested continuously for leakage.

(3) Good general ventilation should be provided to all workrooms.

(4) Only personnel trained in the handling of extra hazardous materials should be employed.

IV. Specific Procedures

A. FIRST AID: Provide bed rest, and administer therapeutic oxygen until a physician arrives.

B. BIOCHEMICAL ASSAY: Urine determinations, using the method of Alexander, *et al*,[1] are valuable to verify exposure.

C. SPECIAL MEDICAL PROCEDURES: Hospitalization, with observation for delayed pulmonary edema, is necessary in all cases. BAL has been suggested for treatment, with a dosage schedule,[5,8] but its effectiveness is questionable.[7] Periodic examinations of all potentially exposed personnel should be made, with particular reference to any persons showing signs of chronic respiratory symptoms.

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Because of space limitations, it is impossible to list all methods of exposure evaluation. The selections have been made on the basis of current usage, reliability, and applicability to the usual industrial type of exposure. Any specific evaluation and/or control problem will involve professional judgment. This can best be done by professional industrial hygiene personnel.

Respiratory protective devices are commercially available. Their use, however, should be confined to emergency or intermittent exposures and not relied upon as primary means of hazard control.

A relative scale is used for rating the severity of hazards: nil, low, moderate, high, and extra hazardous.

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INDIVIDUAL Hygienic Guides in loose-leaf form may be obtained from the American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan, at 25c each. Discount of 20% allowed on orders of five or more; 40% on orders of 100 or more. Also available are flexible loose-leaf binders for the loose Hygienic Guide sheets. The binders have been especially designed to provide maximum protection and ease of handling of the Guides. They will be especially useful in keeping a permanent file. The binders are blue in color, with white lettering, and are fitted with ¾" rings. The price is $1.25. The Guides and the binders may be ordered on the blank below.

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◆ *President's Page*

THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION'S Board of Directors held its mid-year meeting in Pittsburgh November 14. Several of the subjects considered, because of their bearing upon the future of our ASSOCIATION and profession, are briefly covered below.

The Industrial Associate Membership Program has now entered the second stage. Eighteen districts have been set up, each covering a specific geographic territory. Most of the district chairmen have been appointed and are now organizing subcommittees for their respective districts. This program will be described in a future newsletter.

The progress of the technical committees is encouraging. In addition to the Hygienic Guides, one or two technical committee manuals will be completed in 1957. Ways and means to have these manuals published are now under study.

An *ad hoc* AIHA-ACGIH committee has been appointed to appraise current problems in the field of personal protective devices. Respirators will be given priority by this committee. The AIHA program will also devote a special session to this subject at the St. Louis Industrial Health Conference.

The questions of professional certification and registration in the field of industrial hygiene were discussed at length. It was difficult to do any more at our meeting than comprehend the complexity of this problem. Committees have been established to analyze the current situation and to make recommendations to the Board of Directors. These recommendations, in turn, will be submitted to the AIHA membership so the Board may act in accordance with the membership's decision. In the meanwhile, any comments or suggestions on the subject will be welcome.

Lester V. Cralley

✦ News of Local Sections

Philadelphia

PERSONAL NOTES: G. B. MEYERS, M.D., is now plant physician at RCA-Victor, Camden, New Jersey. . . . THOMAS McGRAW, M.D., has been appointed Supervising Physician for the Philadelphia operations of Electric Storage Battery Company . . . . WILLIAM M. PALLIES is now Manager of Industrial Hygiene & Safety in the Public & Industrial Relations Department, Electric Storage Battery Company . . . . EDWARD BAIER has been appointed Assistant Director, Division of Industrial Hygiene, Department of Health, Commonwealth of Pennsylvania . . . . WILLIAM E. SHOEMAKER, JR., recently attained all the requirements for C.P.C.U. designation which will be conferred upon him in Philadelphia late this year . . . . EMMA E. MacDONALD, R.N., has retired after 35 years as industrial nurse for John R. Evans & Company; during which time she made many outstanding contributions in the field of industrial nursing . . . . JOSEPH SHILEN, M.D., was the featured speaker on air pollution before the Delaware Valley Chamber of Commerce, October 16.

Rocky Mountain

THE ANNUAL MEETING of the Rocky Mountain Section was held October 19 and 20, in Pueblo, Colorado. On October 19, a tour was made through the Pueblo Plant of the Colorado Fuel and Iron Corporation. That evening a dinner meeting was held and DUNCAN HOLADAY addressed the group. He discussed his recent trip to the copper mines of South Africa and dwelt particularly on the studies of silicosis which have been made in South Africa over the past 25 years.

On October 20, a scientific and business meeting was held. Papers were presented dealing with the shipment of radioactive materials, uranium toxicity, air pollution control, and problems of personal respiratory protection. The Section unanimously approved a resolution endorsing the work of the Joint Committee on Personal Respiratory Protective Equipment.

Officers elected for the forthcoming year are: EDWIN C. HYATT, President-Elect; SHERMAN S. PINTO, M.D., Secretary-Treasurer; JAMES C. GILLILAND, Director.

St. Louis

ON SEPTEMBER 25, SELDON E. BROWN, attorney, spoke to the St. Louis Section on workmen's compensation in Missouri. MR. BROWN'S talk evoked lively discussion among the 33 members and guests who attended.

The speaker at the meeting November 27, was LESTER V. CRALLEY, Ph.D., AIHA President. AIHA President-Elect, CHARLES R. WILLIAMS, Ph.D. will be the speaker at the meeting January 22.

Southern California

ON NOVEMBER 8, the Southern California Section held a joint meeting with both the Industrial Section and the General Practice Section of the Los Angeles County Medical Association. The speaker was ROBERT A. KEHOE, M.D., Professor of Preventive Medicine and Industrial Health, University of Cincinnati, whose subject was "The Significance of Lead in the Atmosphere." LESLIE A. CHAMBERS, Ph.D., Director of Research, Los Angeles County Air Pollution Control, and ALBERT L. CHANEY, Director of Chaney Laboratories, Inc., lead the discussion following the presentation by DR. KEHOE.

Western New York

AN ALL-DAY meeting of the Western New York Section was held in Buffalo September 28. DR. GEORGE EDDY, Carborundum Company, spoke on "Research on Silicosis and Pneumoconiosis in the Grinding Wheel Industry" and "A Report on the Status of Legislation in New York State for Partial Disability from Silicosis." "Study of Motor Cleaning Solvents—Substitutes for Carbon Tetrachloride" was the title of the paper presented by JOHN MURRAY of the Western Electric Company. HERBERT MILLER of the Bethlehem Steel Company discussed "Industrial Health Engineering in the Design of Chemical Plants," and DR. J. NEWELL STANNARD of the University of Rochester School of Medicine and Dentistry spoke on

"Maximum Permissible Exposure Levels to Radiation in the Light of the National Academy of Science—National Research Council Committee Reports."

Chicago

ON SEPTEMBER 5, G. M. GLIDDEN, General Manager, Acme Protection Equipment Company, spoke to the Chicago Section on "Some Basic Problems Governing the Design of Respiratory Equipment." His interesting chalk-talk presentation showed the development over the years of respiratory equipment from its initial crude design to the present effective devices with which we are familiar.

EDWARD C. HOLMBLAD, M.D., Medical Director, Chicago Plants Division, Eastman Kodak Company, was the speaker at the October 3 meeting. His presentation on "Importance of Teamwork in the Industrial Medical Services" received good audience attention and prompted an interesting question and answer session.

At the meeting November 7, HERBERT J. WEBER, Director, Safety, Hygiene and Air Pollution Control Program, American Foundrymen's Society, spoke on "How the Foundry Industry Looks at Air Pollution." The difficulties encountered in meeting various code requirements and the high cost of pollution control equipment were discussed.

Michigan (Detroit)

THE MICHIGAN SECTION began its 1956-57 activities with a smorgasbord dinner meeting September 25. GEORGE GAUDEAN, Secretary of the Vehicle Combustion Products Sub-Committee, Automobile Manufacturers Association, addressed the meeting on "A Summary of the Automobile Industry Program in Air Pollution."

New England

AN ALL-DAY meeting of the New England Section was held September 26, at the Brown Derby, Montpelier, Vermont. Papers presented were: "Urinary Trichloroacetic Acid in Workers Exposed to Trichloroethylene"—LEONARD D. PAGNOTTO, Chemist, and HERVEY B. ELKINS, Ph.D., Chief of Laboratory, Division of Occupational Hygiene, Massachusetts Department of Labor and Industries; "Industrial Hygiene Problems in Tunnel Construction"—GEORGE W. BOYLEN, JR., Senior Industrial Hygiene Chemist, Bureau of Industrial Hygiene, Connecticut Department of Health; "Discussion of Tunnelling Operations"—ELISE M. COMPRONI, Junior Industrial Hygienist, Massachusetts Department of Labor and Industries; "Vermont's Experience with Industrial Dust—HARRY B. ASHE, Director, Industrial Hygiene Division, Vermont Department of Health; "Current Trends in AIHA" —LESTER V. CRALLEY, Ph.D., President, AIHA; Motion picture: "The Will to Remember" —Barre Granite Association. Following the formal program a business meeting was held and the day's activities were concluded with a trip to the Rock of Ages quarry and manufacturing plant.

The next meeting of the Section is to be held in Boston, in the fall of 1957. JOSEPH A. HOUGHTON of Liberty Mutual Insurance Company was elected Chairman for the coming year, and JOHN B. SKINNER, American Mutual Liability Insurance Company, was re-elected Secretary and Treasurer.

New Jersey

THE FIRST regular fall meeting of the New Jersey Section AIHA was held at the Chiam Chateau in Mountainside, New Jersey, on October 18. WILLIAM F. WEBER, former Industrial Hygienist at the Western Electric Kearny Works, was honored in observance of his retirement after 30 years service with the company. MRS. WEBER and the wives of the members of the New Jersey Section were also present. DR. NORMAN G. WHITE of the Shell Union Oil Company, New York, presented an interesting program, showing colored slides of a tour of Europe.

PERSONAL NOTES: GEORGE D. WARE, MR. WEBER'S former assistant at the Western Electric Company, has been promoted to the position of Industrial Hygienist and PETER J. O'DAY of the Chemical Laboratory has moved into the post formerly held by MR. WARE. . . . DONALD B. ROBINSON, former assistant industrial hygienist at Merck and Company, Rahway, New Jersey, is now associated with the American Cyanamid Company as industrial hygiene chemist at their Stamford Research Laboratories. . . . HENRY A. QUINO, formerly with the State of Maryland Industrial Hygiene Division, has joined Esso Standard Oil Company as an assistant to GEORGE M. WILKENING.

Speakers' table at the October 30 meeting of the Washington-Baltimore Section. Left to right: Dr. Stacy R. Guild, Dr. Anna M. Baetjer, Charles D. Yaffe, George S. Reichenbach, Henry N. Doyle, and Charles P. Bergtholdt.

Washington-Baltimore Section

ON OCTOBER 30, the Washington-Baltimore Section held a meeting in Baltimore with 42 members and guests present. The speaker was CHARLES D. YAFFE, of the United Public Health Service of Cincinnati, who spoke on "Noise, Measurement and Control." MR. YAFFE used a tape recording of some common industrial noises to aid the members and guests to understand fully the problem. An instructive discussion followed his talk.

GEORGE S. REICHENBACH is Chairman of the new committee on the membership drive for the Washington-Baltimore section and has appointed HENRY N. DOYLE, CHARLES E. COUCHMAN, WILLIAM F. REINDOLLAR and JOSEPH G. GASKILL to assist him.

Ohio Valley

PERSONAL NOTES: RONALD BALES has been transferred from the Occupational Health Field Headquarters of the Public Health Service to their Salt Lake City Station. . . . ROBERT CHRISTMAN formerly with the Occupational Health Field Headquarters in Cincinnati is now located with Westinghouse in Pittsburgh. . . . ROBERT HARRIS, on loan from the Occupational Health Program of the Public Health Service to the Kentucky State Health Department is now located at Headquarters in Washington, D.C. . . . JIM MARTIN former Industrial Hygienist, ANP Project of General Electric, Evendale, Ohio, is now associated with Pratt-Whitney, Middletown, Connecticut. . . . RALPH HOFFER has moved into the post formerly held by MR. MARTIN. . . . ED ALPAUGH at National Lead of Ohio has been placed in charge of their Health and Safety Laboratory. . . . FRANCIS BOONE, of the same company is at Harvard School of Public Health this year.

North Texas

AT THE first meeting of the North Texas Section for the 1956-57 year, held September 24, noise was the subject of discussion. Following a demonstration of the Soundscope, a panel consisting of MORT KINTZ, DR. R. J. POTTS and R. A. COUGHLIN, discussed "Problems of Noise in Industry." The discussion concerned means of noise reduction, use of personal protective devices and determination of hearing loss. Each person attending the meeting was given a copy of "Regulations on Radiation Exposure," recently adopted by the Texas State Board of Health. CHARLES W. REED has been elected Chairman-Elect to fill the vacancy caused by the resignation of R. J. POTTS, M.D.

Georgia

THE GEORGIA SECTION was entertained by The Lockheed Aircraft Corporation, Marietta, Georgia, on September 17, with a dinner and plant tour.

On November 5, a dinner meeting was held at Georgia Tech. W. R. RHOADS, Director, Lockheed Nuclear Laboratory, discussed the Dawsonville Project.

At the dinner meeting December 3, the speaker was H. L. PRICE, Director, Division of Civilian Application Atomic Energy Commission, Washington, D.C. His talk concerned Radiation Protection Legislation. It is believed desirable that the Southeastern States should work closely together in pre-

paring adequate and effective radiation protection legislation with the guidance of the AEC and USPHS.

Pacific Northwest

THIS new Section of AIHA includes the states of Washington, Oregon and Idaho. Officers for 1956-57 are CLARENCE P. SKILLERN, President; M. CHAIN ROBBINS, President-Elect; JOHN B. PATE, Secretary-Treasurer; WALTER H. POPPE and G. VICTOR BEARD, Directors.

At the meeting September 9, AIHA President L. V. CRALLEY attended and outlined the aims and program of AIHA. Papers presented were: "Hazardous Materials Control Program at Boeing"—WALTER H. POPPE, JR.; "Problems in the Program of Hazard-Rating Industrial Solvents"—ROSS N. KUSIAN; "Basic Methods for Evaluating Hazards from Possible Reactor Incidents"—G. VICTOR BEARD; and "Investigations of the Psittacosis Hazard to Poultry and Rendering Plant Employees"—KENNETH N. FLOCKE.

PERSONAL NOTE: GENE B. TRUCANO, formerly with the Washington State Department of Labor and Industries, has joined the staff of the Industrial Hygiene Unit at Boeing Airplane Company, Seattle.

✦ Selected Titles and Abstracts

—FROM FOREIGN EXCHANGE JOURNALS

THE FOLLOWING is a partial list of articles, by titles and authors, from journals received by the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION since the September, 1956, issue of the QUARTERLY in exchange for copies of the QUARTERLY.

Additional information on any of the journals or articles may be obtained from: Carrol S. Weil, Senior Industrial Fellow, Mellon Institute of Industrial Research, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

I. WORLD HEALTH ORGANIZATION PUBLICATIONS.

Toxic Hazards of Certain Pesticides to Man. J. M. Barnes, Monograph Series No. 16, 1953 (second impression); 129 pages, bibliography ($1.50).

This monograph describes the hazard of manufacture and application of pesticides as well as that from traces of them left in food products. A list of 700 bibliographical references on these toxic hazards for man and mammals is included.

Occupational Health. Bulletin of the World Health Organization, 1955, Vol. 13, No. 4; 252 pages, 13 figures, 15 tables ($2.00).

This contains 17 papers on various current problems in the field of occupational health. It deals with pre-employment and periodical health examinations, absenteeism, mental health in industry, the health problems of old workers, the rehabilitation of physically handicapped workers, industrial accidents and their prevention, etc.

II. CHRONICLE OF THE WORLD HEALTH ORGANIZATION, Vol. 10, No. 8 (1956).

Toxicity of Pentachlorophenol, p. 247.

An increasing amount of evidence has accumulated to indicate that pentachlorophenol is quite toxic. Reports have been received of fatalities among men handling it as a timber dressing (see TRUHAUT, R., L'EPEE, P., and BOUSSEMART, E.: *Arch. Mal. prof.*, 13:567, 1952.) In all cases the environmental temperature has been high. The features of poisoning are profuse sweating and thirst, with rapid collapse and death in some cases. The similarity to poisoning by DNC (4,6-dinitro-o-cresol) can be explained on the basis of similar biochemical action of the two compounds.

Food Additives, p. 259.

A brief abstract is presented of the "World Health Organization" technical Report Series, 1956, 107, 14-page ($.30) article. This is a report issued in September, 1955, of a joint conference on food additives of the FAO and WHO. It outlines the advantages and specific lines of action of international action with regard to these additives. Those singled out as deserving priority are food colors, preservatives (antimicrobial agents and antioxidants), and emulsifiers, in that order.

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Instruments for the Study of Atmospheric Pollution

THE AMERICAN Society of Mechanical Engineers has published a booklet designed to help those interested in obtaining equipment suitable for the study of air pollution problems. The booklet lists hundreds of devices which are useful in the study of all facets of this important problem, together with the names and addresses of manufacturers who can supply them. The Committee on Air Pollution Controls of the ASME spent eight months compiling this comprehensive report. The new booklet, entitled "Instruments For The Study Of Atmospheric Pollution," is available from the ASME Order Department, 29 West 39th Street, New York 18, at a cost of $2.00 per copy.